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(54) **METHOD AND PRECODER INFORMATION FEEDBACK IN MULTI-ANTENNA WIRELESS COMMUNICATION SYSTEMS**

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CPC *H04B 7/0456* (2013.01); *H04B 7/0469* (2013.01); *H04B 7/0478* (2013.01); *H04B 7/0486* (2013.01); *H04B 7/0639* (2013.01)

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(56) **References Cited**

U.S. PATENT DOCUMENTS

4,612,669 A	9/1986	Nossen	
4,631,543 A	12/1986	Brodeur	

(Continued)

FOREIGN PATENT DOCUMENTS

CN	1762137	4/2006
CN	1859656	11/2006

(Continued)

OTHER PUBLICATIONS

"3rd Generation Partnership Project; Technical Specification Group Radio Access Network", 3GPP TR 36.814 V9.0.0 (Mar. 2010), Further Advancements for E-UTRA Physical Layer Aspects (Release 9), Mar. 2010, 104 pages.

(Continued)

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(57) **ABSTRACT**

A method for two component feedback in wireless communication systems is disclosed, with a wireless communication device sending a first representation of a first matrix chosen from a first codebook, wherein the first matrix has at least two columns, the wireless communication device sending a second representation of a second matrix chosen from a second codebook, and the base station obtaining a precoder from the first representation and the second representation.

31 Claims, 6 Drawing Sheets

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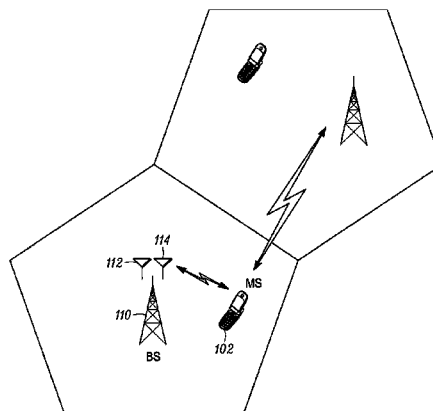
(56) **References Cited**

U.S. PATENT DOCUMENTS

4,754,285 A	6/1988	Robitaille
4,881,123 A	11/1989	Chapple
4,884,252 A	11/1989	Teodoridis et al.
5,267,234 A	11/1993	Harrison
5,459,440 A	10/1995	Claridge et al.
5,564,086 A	10/1996	Cygan et al.
5,634,200 A	5/1997	Kitakubo et al.
5,649,307 A	7/1997	Patino
5,699,319 A	12/1997	Skrivervik
5,757,326 A	5/1998	Koyama et al.
5,804,944 A	9/1998	Alberkrack et al.
5,862,458 A	1/1999	Ishii
6,144,186 A	11/2000	Thandiwe et al.
6,339,758 B1	1/2002	Kanazawa et al.
6,362,690 B1	3/2002	Tichauer
6,373,439 B1	4/2002	Zurcher et al.
6,400,702 B1	6/2002	Meier
6,560,444 B1	5/2003	Imberg
6,594,508 B1	7/2003	Ketonen
6,674,291 B1	1/2004	Barber et al.
6,879,942 B1	4/2005	Nagase et al.
6,927,555 B2	8/2005	Johnson
6,937,980 B2	8/2005	Krasny et al.
7,019,702 B2	3/2006	Henriet et al.
7,142,884 B2	11/2006	Hagn
7,199,754 B2	4/2007	Krumm et al.
7,202,815 B2	4/2007	Swope et al.
7,224,992 B2	5/2007	Patino et al.
7,254,420 B1	8/2007	Klein
7,260,366 B2	8/2007	Lee et al.
7,359,504 B1	4/2008	Reuss et al.
7,400,907 B2	7/2008	Jin et al.
7,433,661 B2	10/2008	Kogiantis et al.
7,436,896 B2	10/2008	Hottinen et al.
7,440,731 B2	10/2008	Staudinger et al.
7,471,963 B2	12/2008	Kim et al.
7,486,931 B2	2/2009	Cho et al.
7,504,833 B1	3/2009	Sequine
7,599,420 B2	10/2009	Forenza et al.
7,620,432 B2	11/2009	Willins et al.
D606,958 S	12/2009	Knoppert et al.
7,639,660 B2	12/2009	Kim et al.
7,643,642 B2	1/2010	Patino et al.
7,649,831 B2	1/2010	Van Rensburg et al.
7,664,200 B2	2/2010	Ariyavisitakul et al.
7,746,943 B2	6/2010	Yamaura
7,760,681 B1	7/2010	Chhabra
7,773,535 B2	8/2010	Vook et al.
7,773,685 B2	8/2010	Tirkkonen et al.
7,813,696 B2	10/2010	Kim
7,822,140 B2	10/2010	Catreux et al.
7,835,711 B2	11/2010	McFarland
7,839,201 B2	11/2010	Jacobson
7,885,211 B2	2/2011	Shen et al.
7,936,237 B2	5/2011	Park et al.
7,940,740 B2	5/2011	Krishnamurthy et al.
7,942,936 B2	5/2011	Golden
7,945,229 B2	5/2011	Wilson et al.
7,983,722 B2	7/2011	Lowles et al.
8,014,455 B2	9/2011	Kim et al.
8,072,285 B2	12/2011	Spears et al.
8,094,011 B2	1/2012	Faris et al.
8,095,081 B2	1/2012	Vance
8,098,120 B2	1/2012	Steeneken et al.
8,155,683 B2	4/2012	Buckley et al.
8,204,446 B2	6/2012	Scheer et al.
8,219,336 B2	7/2012	Hoebel et al.
8,219,337 B2	7/2012	Hoebel et al.
8,232,685 B2	7/2012	Perper et al.
8,233,851 B2	7/2012	Jeon et al.
8,244,317 B2	8/2012	Knoppert et al.
8,259,431 B2	9/2012	Katta
8,275,327 B2	9/2012	Yi et al.
8,280,038 B2	10/2012	Johnson et al.
8,280,323 B2	10/2012	Thompson
8,284,849 B2	10/2012	Lee et al.
8,302,183 B2	10/2012	Sood
8,319,393 B2	11/2012	DeReus
8,373,596 B1	2/2013	Kimball et al.
8,374,633 B2	2/2013	Frank et al.
8,384,695 B2	2/2013	Lee et al.
8,428,022 B2	4/2013	Frank et al.
8,460,961 B2	6/2013	Guo et al.
8,483,707 B2	7/2013	Krishnamurthy et al.
8,509,338 B2	8/2013	Sayana et al.
8,542,776 B2	9/2013	Kim et al.
8,588,426 B2	11/2013	Xin et al.
8,594,584 B2	11/2013	Greene et al.
8,606,200 B2	12/2013	Ripley et al.
8,611,829 B2	12/2013	Alberth et al.
8,620,348 B2	12/2013	Shrivastava et al.
8,626,083 B2	1/2014	Greene et al.
8,712,340 B2	4/2014	Hoirup et al.
8,712,355 B2	4/2014	Black et al.
8,731,496 B2	5/2014	Drogi et al.
8,761,296 B2	6/2014	Zhang et al.
8,767,722 B2	7/2014	Kamble et al.
8,909,173 B2	12/2014	Harmke
8,989,747 B2	3/2015	Padden et al.
9,002,354 B2	4/2015	Krishnamurthy et al.
9,031,523 B2	5/2015	Anderson
9,197,255 B2	11/2015	Pourkhaatoun et al.
9,203,489 B2	12/2015	Sayana et al.
9,215,659 B2	12/2015	Asrani et al.
9,241,050 B1	1/2016	Asrani et al.
9,298,303 B2	3/2016	Wagner et al.
9,301,177 B2	3/2016	Ballantyne et al.
9,326,320 B2	4/2016	Hong et al.
9,344,837 B2	5/2016	Russel et al.
2001/0034238 A1	10/2001	Voyer
2002/0037742 A1	3/2002	Enderlein et al.
2002/0057751 A1	5/2002	Jagger et al.
2002/0090974 A1	7/2002	Hagn
2002/0138254 A1	9/2002	Isaka et al.
2002/0149351 A1	10/2002	Kanekawa et al.
2002/0193130 A1	12/2002	Yang et al.
2003/0143961 A1	7/2003	Humphreys et al.
2003/0161485 A1	8/2003	Smith
2003/0222819 A1	12/2003	Karr et al.
2004/0051583 A1	3/2004	Hellberg
2004/0052314 A1	3/2004	Copeland
2004/0052317 A1	3/2004	Love et al.
2004/0057530 A1	3/2004	Tarokh et al.
2004/0063439 A1	4/2004	Glazko et al.
2004/0082356 A1	4/2004	Walton et al.
2004/0106428 A1	6/2004	Shoji
2004/0148333 A1	7/2004	Manion et al.
2004/0176125 A1	9/2004	Lee
2004/0178912 A1	9/2004	Smith et al.
2004/0192398 A1	9/2004	Zhu
2004/0198392 A1	10/2004	Harvey et al.
2004/0235433 A1	11/2004	Hugl et al.
2004/0246048 A1	12/2004	Leyonhjelm et al.
2005/0037733 A1	2/2005	Coleman et al.
2005/0041018 A1	2/2005	Philipp
2005/0075123 A1	4/2005	Jin et al.
2005/0124393 A1	6/2005	Nuovo et al.
2005/0134456 A1	6/2005	Niu et al.
2005/0135324 A1	6/2005	Kim et al.
2005/0136845 A1	6/2005	Masuoka et al.
2005/0208952 A1	9/2005	Dietrich et al.
2005/0227640 A1	10/2005	Haque et al.
2005/0250532 A1	11/2005	Hwang et al.
2006/0019677 A1	1/2006	Teague et al.
2006/0052131 A1	3/2006	Ichihara
2006/0067277 A1	3/2006	Thomas et al.
2006/0077952 A1	4/2006	Kubsch et al.
2006/0099940 A1	5/2006	Pfleging et al.
2006/0103635 A1	5/2006	Park
2006/0181453 A1	8/2006	King et al.
2006/0194593 A1	8/2006	Drabeck et al.
2006/0207806 A1	9/2006	Philipp
2006/0209754 A1	9/2006	Ji et al.
2006/0215618 A1	9/2006	Soliman et al.

(56)   **References Cited**

U.S. PATENT DOCUMENTS

2006/0240827	A1	10/2006	Dunn
2006/0245601	A1	11/2006	Michaud et al.
2006/0256887	A1	11/2006	Kwon et al.
2006/0280261	A1	12/2006	Prikhodko et al.
2006/0291393	A1	12/2006	Teague et al.
2006/0292990	A1	12/2006	Karabinis et al.
2007/0004344	A1	1/2007	DeGroot et al.
2007/0008108	A1	1/2007	Schurig et al.
2007/0026838	A1	2/2007	Staudinger et al.
2007/0042714	A1	2/2007	Ayed
2007/0049280	A1	3/2007	Sambhwani et al.
2007/0069735	A1	3/2007	Graf et al.
2007/0091004	A1	4/2007	Puuri
2007/0093281	A1	4/2007	Park et al.
2007/0133462	A1	6/2007	Guey
2007/0153743	A1	7/2007	Mukkavilli et al.
2007/0197180	A1	8/2007	McKinzie et al.
2007/0200766	A1	8/2007	McKinzie et al.
2007/0211657	A1	9/2007	McBeath et al.
2007/0211813	A1	9/2007	Talwar et al.
2007/0222629	A1	9/2007	Yoneyama
2007/0223422	A1	9/2007	Kim et al.
2007/0232370	A1	10/2007	Kim
2007/0238425	A1	10/2007	McFarland
2007/0238496	A1	10/2007	Chung et al.
2007/0243894	A1	10/2007	Das et al.
2007/0255558	A1	11/2007	Yasunaga et al.
2007/0280160	A1	12/2007	Kim et al.
2007/0285326	A1	12/2007	McKinzie
2008/0001915	A1	1/2008	Pihlaja et al.
2008/0002735	A1	1/2008	Poirier et al.
2008/0014960	A1	1/2008	Chou
2008/0026710	A1	1/2008	Buckley
2008/0080449	A1	4/2008	Huang et al.
2008/0089312	A1	4/2008	Malladi
2008/0095109	A1	4/2008	Malladi et al.
2008/0108310	A1*	5/2008	Tong H04B 7/0617
			455/69
2008/0111714	A1	5/2008	Kremin
2008/0117886	A1	5/2008	Kim
2008/0130626	A1	6/2008	Ventola et al.
2008/0132247	A1	6/2008	Anderson
2008/0133462	A1	6/2008	Aylward et al.
2008/0157893	A1	7/2008	Krah
2008/0159239	A1	7/2008	Odlyzko et al.
2008/0165876	A1	7/2008	Suh et al.
2008/0167040	A1	7/2008	Khandekar et al.
2008/0167073	A1	7/2008	Hobson et al.
2008/0170602	A1	7/2008	Guey
2008/0170608	A1	7/2008	Guey
2008/0186105	A1	8/2008	Scuderi et al.
2008/0192683	A1	8/2008	Han et al.
2008/0212520	A1	9/2008	Chen et al.
2008/0225693	A1	9/2008	Zhang et al.
2008/0227414	A1	9/2008	Karmi et al.
2008/0227481	A1	9/2008	Naguib et al.
2008/0232395	A1	9/2008	Buckley et al.
2008/0267310	A1	10/2008	Khan et al.
2008/0274753	A1	11/2008	Attar et al.
2008/0298482	A1	12/2008	Rensburg et al.
2008/0307427	A1	12/2008	Pi et al.
2008/0309633	A1	12/2008	Hotelling et al.
2008/0313146	A1	12/2008	Wong et al.
2008/0317259	A1	12/2008	Zhang et al.
2009/0041151	A1	2/2009	Khan et al.
2009/0055170	A1	2/2009	Nagahama
2009/0061790	A1	3/2009	Rofougaran
2009/0061887	A1	3/2009	Hart et al.
2009/0067382	A1	3/2009	Li et al.
2009/0091551	A1	4/2009	Hotelling et al.
2009/0102294	A1	4/2009	Hodges et al.
2009/0121963	A1	5/2009	Greene
2009/0122758	A1	5/2009	Smith et al.
2009/0122884	A1	5/2009	Vook et al.
2009/0228598	A1	9/2009	Stamoulis et al.
2009/0238131	A1	9/2009	Montojo et al.
2009/0243631	A1	10/2009	Kuang
2009/0252077	A1	10/2009	Khandekar et al.
2009/0256644	A1	10/2009	Knudsen
2009/0258614	A1	10/2009	Walker
2009/0262699	A1	10/2009	Wdngerter et al.
2009/0264078	A1	10/2009	Yun et al.
2009/0268675	A1	10/2009	Choi
2009/0270103	A1	10/2009	Pani et al.
2009/0285321	A1	11/2009	Schulz et al.
2009/0290544	A1	11/2009	Yano et al.
2009/0295226	A1	12/2009	Hodges et al.
2009/0298433	A1	12/2009	Sorrells et al.
2009/0307511	A1	12/2009	Fiennes et al.
2009/0323608	A1	12/2009	Adachi et al.
2010/0002657	A1	1/2010	Teo et al.
2010/0023898	A1	1/2010	Nomura et al.
2010/0034312	A1	2/2010	Muharemovic et al.
2010/0035627	A1	2/2010	Hou et al.
2010/0046460	A1	2/2010	Kwak et al.
2010/0046650	A1	2/2010	Jongren et al.
2010/0056166	A1	3/2010	Tenny
2010/0085010	A1	4/2010	Suzuki et al.
2010/0103949	A1	4/2010	Jung et al.
2010/0106459	A1	4/2010	Bakalov
2010/0109796	A1	5/2010	Park et al.
2010/0118706	A1	5/2010	Parkvall et al.
2010/0118839	A1	5/2010	Malladi et al.
2010/0156728	A1	6/2010	Alvey et al.
2010/0157858	A1	6/2010	Lee et al.
2010/0157924	A1	6/2010	Prasad et al.
2010/0159833	A1	6/2010	Lewis et al.
2010/0161658	A1	6/2010	Hamynen et al.
2010/0165882	A1	7/2010	Palanki et al.
2010/0167743	A1	7/2010	Palanki et al.
2010/0172310	A1	7/2010	Cheng et al.
2010/0172311	A1	7/2010	Agrawal et al.
2010/0182903	A1	7/2010	Palanki et al.
2010/0189191	A1	7/2010	Taoka et al.
2010/0195566	A1	8/2010	Krishnamurthy et al.
2010/0208838	A1	8/2010	Lee et al.
2010/0217590	A1	8/2010	Nemer et al.
2010/0220801	A1	9/2010	Lee et al.
2010/0260154	A1	10/2010	Frank et al.
2010/0271330	A1	10/2010	Philipp
2010/0272094	A1	10/2010	Byard et al.
2010/0311437	A1	12/2010	Palanki et al.
2010/0317343	A1	12/2010	Krishnamurthy
2010/0322176	A1	12/2010	Chen et al.
2010/0323718	A1	12/2010	Jen
2011/0039583	A1	2/2011	Frank et al.
2011/0051834	A1	3/2011	Lee et al.
2011/0080969	A1	4/2011	Jongren et al.
2011/0083066	A1	4/2011	Chung et al.
2011/0085588	A1	4/2011	Zhuang et al.
2011/0085610	A1	4/2011	Zhuang et al.
2011/0096739	A1	4/2011	Heidari et al.
2011/0103498	A1	5/2011	Chen et al.
2011/0105023	A1	5/2011	Scheer
2011/0116423	A1	5/2011	Rousu et al.
2011/0116436	A1	5/2011	Bachu et al.
2011/0117925	A1	5/2011	Sampath et al.
2011/0119005	A1	5/2011	Majima et al.
2011/0121836	A1	5/2011	Kim et al.
2011/0143770	A1	6/2011	Charbit et al.
2011/0143773	A1	6/2011	Kangas et al.
2011/0148625	A1	6/2011	Velusamy
2011/0148700	A1	6/2011	Lasagabaster et al.
2011/0149868	A1	6/2011	Krishnamurthy et al.
2011/0149903	A1	6/2011	Krishnamurthy et al.
2011/0157067	A1	6/2011	Wagner et al.
2011/0158200	A1	6/2011	Bachu et al.
2011/0176252	A1	7/2011	DeReus
2011/0189964	A1	8/2011	Jeon et al.
2011/0190016	A1	8/2011	Hamabe et al.
2011/0216840	A1	9/2011	Lee et al.
2011/0244884	A1	10/2011	Kangas et al.
2011/0249637	A1*	10/2011	Hammarwall H04B 7/0634
			370/329

(56) **References Cited**

U.S. PATENT DOCUMENTS

2011/0250852 A1	10/2011	Greene
2011/0263303 A1	10/2011	Lowles et al.
2011/0268101 A1	11/2011	Wang
2011/0274188 A1	11/2011	Sayana et al.
2011/0281532 A1	11/2011	Shin et al.
2011/0285603 A1	11/2011	Skarp
2011/0286349 A1	11/2011	Tee et al.
2011/0292844 A1	12/2011	Kwun et al.
2011/0319027 A1	12/2011	Sayana
2012/0002609 A1	1/2012	Larsson et al.
2012/0008510 A1	1/2012	Cai et al.
2012/0021769 A1	1/2012	Lindoff et al.
2012/0032646 A1	2/2012	Lee
2012/0039251 A1	2/2012	Sayana
2012/0050122 A1	3/2012	Wu et al.
2012/0052903 A1	3/2012	Han et al.
2012/0071195 A1	3/2012	Chakraborty et al.
2012/0076043 A1	3/2012	Nishio et al.
2012/0077538 A1	3/2012	Yun
2012/0106475 A1	5/2012	Jung
2012/0112851 A1	5/2012	Manssen et al.
2012/0120772 A1	5/2012	Fujisawa
2012/0120934 A1	5/2012	Cho
2012/0122478 A1	5/2012	Siomina et al.
2012/0158839 A1	6/2012	Hassan et al.
2012/0161927 A1	6/2012	Pierfelice et al.
2012/0162129 A1	6/2012	Krah et al.
2012/0170541 A1	7/2012	Love et al.
2012/0177089 A1	7/2012	Pelletier et al.
2012/0178370 A1	7/2012	George
2012/0182144 A1	7/2012	Richardson et al.
2012/0206556 A1	8/2012	Yu et al.
2012/0214412 A1	8/2012	Schlub et al.
2012/0214421 A1	8/2012	Hoirup et al.
2012/0214549 A1	8/2012	Philbin
2012/0220243 A1	8/2012	Mendolia
2012/0295554 A1	11/2012	Greene et al.
2012/0295555 A1	11/2012	Greene et al.
2012/0302188 A1	11/2012	Sahota et al.
2012/0306716 A1	12/2012	Satake et al.
2012/0309388 A1	12/2012	Moosavi et al.
2012/0309413 A1	12/2012	Grosman et al.
2012/0316967 A1	12/2012	Mgrdechian et al.
2013/0030803 A1	1/2013	Liao
2013/0034241 A1	2/2013	Pandey et al.
2013/0039284 A1	2/2013	Marinier et al.
2013/0040578 A1	2/2013	Khoshnevis et al.
2013/0059600 A1	3/2013	Elsom-Cook et al.
2013/0078980 A1	3/2013	Saito
2013/0094484 A1	4/2013	Kneckt et al.
2013/0109314 A1	5/2013	Kneckt et al.
2013/0109334 A1	5/2013	Kwon et al.
2013/0142113 A1	6/2013	Fong et al.
2013/0150092 A1	6/2013	Frank et al.
2013/0178175 A1	7/2013	Kato
2013/0194154 A1	8/2013	Baliarda et al.
2013/0195283 A1	8/2013	Larson et al.
2013/0195296 A1	8/2013	Merks
2013/0231151 A1	9/2013	Kneckt et al.
2013/0286937 A1	10/2013	Liu et al.
2013/0307735 A1	11/2013	Contreras et al.
2013/0310102 A1	11/2013	Chao et al.
2013/0316687 A1	11/2013	Subbaramoo et al.
2013/0322375 A1	12/2013	Chang et al.
2013/0322562 A1	12/2013	Zhang et al.
2013/0325149 A1	12/2013	Manssen et al.
2014/0024321 A1	1/2014	Zhu et al.
2014/0044126 A1	2/2014	Sabhanatarajan et al.
2014/0068288 A1	3/2014	Robinson et al.
2014/0092830 A1	4/2014	Chen et al.
2014/0093091 A1	4/2014	Dusan et al.
2014/0185498 A1	7/2014	Schwent et al.
2014/0227981 A1	8/2014	Pecen et al.
2014/0273882 A1	9/2014	Asrani et al.
2014/0273886 A1	9/2014	Black et al.
2014/0313088 A1	10/2014	Rozenblit et al.
2014/0349593 A1	11/2014	Danak et al.
2014/0376652 A1	12/2014	Sayana et al.
2014/0379332 A1	12/2014	Rodriguez et al.
2015/0017978 A1	1/2015	Hong et al.
2015/0024786 A1	1/2015	Asrani et al.
2015/0031420 A1	1/2015	Higaki et al.
2015/0072632 A1	3/2015	Pourkhaatoun et al.
2015/0080047 A1	3/2015	Russell et al.
2015/0092954 A1	4/2015	Coker et al.
2015/0171919 A1	6/2015	Ballantyne et al.
2015/0181388 A1	6/2015	Smith
2015/0236828 A1	8/2015	Park et al.
2015/0245323 A1	8/2015	You et al.
2015/0280876 A1	10/2015	You et al.
2015/0312058 A1	10/2015	Black et al.
2015/0349410 A1	12/2015	Russell et al.
2015/0365065 A1	12/2015	Higaki et al.
2016/0014727 A1	1/2016	Nimbalker
2016/0036482 A1	2/2016	Black et al.

FOREIGN PATENT DOCUMENTS

CN	1984476	6/2007
CN	101035379	9/2007
DE	10053205	5/2002
DE	10118189	11/2002
EP	0695059	1/1996
EP	1158686	11/2001
EP	1298809	4/2003
EP	1357543	10/2003
EP	1511010	3/2005
EP	1753152	2/2007
EP	1443791	2/2009
EP	2487967	8/2012
EP	2255443	11/2012
EP	2557433	2/2013
EP	2568531	3/2013
EP	2590258	5/2013
JP	H09247852	9/1997
JP	2000286924	10/2000
KR	20050058333	6/2005
RU	2005113251	1/2006
WO	WO-9306682	4/1993
WO	WO-9416517	7/1994
WO	WO-9600401	1/1996
WO	WO-9921389	4/1999
WO	WO-9950968	10/1999
WO	WO-0111721	2/2001
WO	WO-03007508	1/2003
WO	WO-03107327	12/2003
WO	WO-2004021634	3/2004
WO	WO-20040040800	5/2004
WO	WO-2004084427	9/2004
WO	WO-2004084447	9/2004
WO	WO-2006039434	4/2006
WO	WO-2006046192	5/2006
WO	WO-2006130278	12/2006
WO	WO 2007052115	5/2007
WO	WO-2007080727	7/2007
WO	WO-2008027705	3/2008
WO	WO-2008033117	3/2008
WO	WO-2008085107	7/2008
WO	WO-2008085416	7/2008
WO	WO-2008085720	7/2008
WO	WO-2008112849	9/2008
WO	WO-2008113210	9/2008
WO	WO-2008137354	11/2008
WO	WO-2008137607	11/2008
WO	WO-2008156081	12/2008
WO	WO-2009107090	9/2009
WO	WO-2010080845	7/2010
WO	WO-2010124244	10/2010
WO	WO-2010138039	12/2010
WO	WO-2012115649	8/2012
WO	WO-2012149968	11/2012

(56)   References Cited

FOREIGN PATENT DOCUMENTS

WO   WO-2012177939   12/2012
WO   WO-2013131268   9/2013

OTHER PUBLICATIONS

"A feedback framework based on W2W1 for Rei. 10", 3GPP TSG RAN WG1 #61bis, R1-103664,, Jun. 2010, 19 pages.
"Addition of PRS Muting Configuration Information to LPPa", 3GPP TSG RAN3 #68, Montreal, Canada; Ericsson, R3-101526, May 2010, 7 pages.
"Best Companion' reporting for improved single-cell MU-MIMO pairing", 3GPP TSG RAN WG1 #56; Athens, Greece; Alcatel-Lucent, R1-090926, Feb. 2009, 5 pages.
"Change Request—Clarification of the CP length of empty OFDM symbols in PRS subframes", 3GPP TSG RAN WG1 #59bis, Jeju, Vaiencia, Spain, ST-Ericsson, Motorola, Qualcomm Inc, R1-100311;, Jan. 2009, 2 pages.
"Change Request 36.211—Introduction of L TE Positioning", 3GPP TSG RAN WG1 #59, Jeju, South Korea; Ericsson, R1-095027, May 2010, 6 pages.
"Change Request 36.213 Clarification of POSCH and PRS in combination for L TE positioning", 3GPP TSG RAN WG1 #58bis, Miyazaki, Japan; Ericsson, et al., R1-094262;, Oct. 2009, 4 pages.
"Change Request 36.214—Introduction of LTE Positioning", 3GPP TSG RAN WG1 #59, Jeju, South Korea, Ericsson, et al., R1-094430, Nov. 2009, 4 pages.
"Companion Subset Based PMI/CQI Feedback for LTE-A MU-MIMO", 3GPP TSG RAN WG1 #60; San Francisco, USA, RIM; R1-101104, Feb. 2010, 8 pages.
"Comparison of PMI-based and SCF-based MU-MIMO", 3GPP TSG RAN1 #58; Shenzhen, China; R1-093421 Aug. 2009, 5 pages.
"Development of two-stage feedback framework for Rel-10", 3GPP TSG RAN WG1 #60bis Meeting, R1-101859, Alcatel-Lucent Shanghai Bell, Alcatel-Lucent, Apr. 2010, 5 pages.
"Digital cellular telecommunications system (Phase 2+)", Location Services (LCS); Broadcast Network Assistance for Enhanced Observed Time Difference (E-OTD) and Global Positioning System (GPS) Positioning Methods (3GPP TS 04.35 version 8.3.0 Release 1999), 2001, 37 pages.
"Discussions on UE positioning issues", 3GPP TSG-RAN WG1 #57 R1-091911, San Francisco, USA,, May 2009, 12 pages.
"DL Codebook design for 8Tx preceding", 3GPP TSG RAN WG1 #60bis, R1-102380, LG Electronics, Beijing, China, Apr. 2010, 4 pages.
"Double codebook design principles", 3GPP TSG RAN WG1 #61bis, R1-103804, Nokia, Nokia Siemens Networks, Dresden, Germany, Jun. 2010, 9 pages.
"Evaluation of protocol architecture alternatives for positioning", 3GPP TSG-RAN WG2 #66bis R2-093855, Los Angeles, CA, USA, Jun. 2009, 4 pages.
"Ex Parte Quayle Action", U.S. Appl. No. 13/088,237, filed Dec. 19, 2012, 5 pages.
"Extended European Search Report", EP Application No. 12196319.3, Feb. 27, 2014, 7 pages.
"Extended European Search Report", EP Application No. 12196328.4, Feb. 26, 2014, 7 pages.
"Extensions to Rel-8 type CQI/PMI/RI feedback using double codebook structure", 3GPP TSG RAN WG1#59bis, R1-100251, Valencia, Spain,, Jan. 2010, 4 pages.
"Feedback Codebook Design and Performance Evaluation", 3GPP TSG RAN WG1 #61bis, R1-103970, LG Electronics, Jun. 2010, 6 pages.
"Feedback considerations for DL MIMO and CoMP", 3GPP TSG RAN WG1 #57bis; Los Angeles, USA; Qualcomm Europe; R1-092695, Jun. 2009, 6 pages.
"Final Office Action", U.S. Appl. No. 12/573,456, Mar. 21, 2012, 12 pages.
"Final Office Action", U.S. Appl. No. 12/756,777, Nov. 1, 2013, 12 pages.
"Final Office Action", U.S. Appl. No. 12/899,211, Oct. 24, 2013, 17 pages.
"Final Rejection", U.S. Appl. No. 12/407,783, Feb. 15, 2012, 18 pages.
"Foreign Office Action", CN Application No. 201080025882.7, Feb. 8, 2014, 19 pages.
"Further details on DL OTDOA", 3GPP TSG RAN WG1 #56bis, Seoul, South Korea—Ericsson, R1-091312,, Mar. 2009, 6 pages.
"Further Refinements of Feedback Framework", 3GPP TSG-RAN WG1 #60bis R1-101742; Ericsson, ST-Ericsson, Apr. 2010, 8 pages.
"IEEE 802.16m System Description Document [Draft]", IEEE 802.16 Broadband Wireless Access Working Group, Nokia, Feb. 7, 2009, 171 pages.
"Implicit feedback in support of downlink MU-MIMO Texas Instruments", 3GPP TSG RAN WG1 #58; Shenzhen, China, R1-093176, Aug. 2009, 4 pages.
"Improving the hearability of LTE Positioning Service", 3GPP TSG RAN WG1 #55bis; Alcatei-Lucent, R1-090053 Jan. 2009, 5 pages.
"International Search Report and Written Opinion", Application No. PCT/US2010/026579, Feb. 4, 2011, 13 pages.
"International Search Report and Written Opinion", Application No. PCT/US2011/034959, Aug. 16, 2011, 13 pages.
"International Search Report and Written Opinion", Application No. PCT/US2011/045209, Oct. 28, 2011, 14 pages.
"International Search Report and Written Opinion", Application No. PCT/US2011/039214, Sep. 14, 2011, 9 pages.
"International Search Report and Written Opinion", Application No. PCT/US2010/038257, Oct. 1, 2010, 9 pages.
"International Search Report and Written Opinion", Application No. PCT/US2010/034023, Dec. 1, 2010, 9 pages.
"International Search Report", Application No. PCT/US2010/030516, Oct. 8, 2010, 5 pages.
"International Search Report", Application No. PCT/US2010/036982, Nov. 22, 2010, 4 pages.
"International Search Report", Application No. PCT/US2010/041451, Oct. 25, 2010, 3 pages.
"International Search Report", Application No. PCT/US2011/044103, Oct. 24, 2011, 3 pages.
"Introduction of L TE Positioning", 3GPP TSG RAN WG1 #58, Shenzhen, China, R1-093604; Draft CR 36.213, Aug. 2009, 3 pages.
"Introduction of L TE Positioning", 3GPP TSG RAN WG1 #59, Jeju, South Korea, Ericsson et al.; R1-094429,, Nov. 2009, 5 pages.
"Introduction of LTE Positioning", 3GPP TSG RAN WG1 #58, Shenzhen, China; Draft CR 36.214; R1-093605;, Aug. 2009, 6 pages.
"Introduction of LTE Positioning", 3GPP TSG-RAN WG1 Meeting #58, R1-093603, Shenzhen, China,, Aug. 2009, 5 pages.
"LS on 12 5. Assistance Information for OTDOA Positioning Support for L TE Rel-9", 3GPP TSG RAN WG1 Meeting #58; Shenzhen, China; R1-093729, Aug. 2009, 3 pages.
"LS on LTE measurement supporting Mobility", 3GPP TSG WG1 #48, Tdoc R1-071250; StLouis, USA, Feb. 2007, 2 pages.
"LTE Positioning Protocol (LPP)", 3GPP TS 36.355 V9.0.0 (Dec. 2009); 3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA); Release 9, Dec. 2009, 102 pages.
"Method for Channel Quality Feedback in Wireless Communication Systems", U.S. Appl. No. 12/823,178, filed Jun. 25, 2010, 34 pages.
"Non-Final Office Action", U.S. Appl. No. 12/407,783, Sep. 9, 2013, 16 pages.
"Non-Final Office Action", U.S. Appl. No. 12/407,783, Oct. 5, 2011, 14 pages.
"Non-Final Office Action", U.S. Appl. No. 12/480,289, Jun. 9, 2011, 20 pages.
"Non-Final Office Action", U.S. Appl. No. 12/492,339, Aug. 19, 2011, 13 pages.
"Non-Final Office Action", U.S. Appl. No. 12/542,374, Feb. 24, 2014, 25 pages.
"Non-Final Office Action", U.S. Appl. No. 12/542,374, Aug. 7, 2013, 22 pages.
"Non-Final Office Action", U.S. Appl. No. 12/542,374, Aug. 31, 2012, 27 pages.
"Non-Final Office Action", U.S. Appl. No. 12/542,374, Dec. 23, 2011, 22 pages.

(56) **References Cited**

OTHER PUBLICATIONS

"Non-Final Office Action", U.S. Appl. No. 12/573,456, Nov. 18, 2011, 9 pages.
"Non-Final Office Action", U.S. Appl. No. 12/577,553, Feb. 4, 2014, 10 pages.
"Non-Final Office Action", U.S. Appl. No. 12/577,553, Aug. 12, 2013, 11 pages.
"Non-Final Office Action", U.S. Appl. No. 12/577,553, Dec. 28, 2011, 7 pages.
"Non-Final Office Action", U.S. Appl. No. 12/756,777, Apr. 19, 2013, 17 pages.
"Non-Final Office Action", U.S. Appl. No. 12/813,221, Oct. 8, 2013, 10 pages.
"Non-Final Office Action", U.S. Appl. No. 12/823,178, Aug. 23, 2012, 15 pages.
"Non-Final Office Action", U.S. Appl. No. 12/899,211, Apr. 10, 2014, 12 pages.
"Non-Final Office Action", U.S. Appl. No. 12/899,211, May 22, 2013, 17 pages.
"Non-Final Office Action", U.S. Appl. No. 12/973,467, Mar. 28, 2013, 9 pages.
"Non-Final Office Action", U.S. Appl. No. 13/759,089, Apr. 18, 2013, 16 pages.
"Non-Final Office Action", U.S. Appl. No. 13/924,838, Nov. 28, 2014, 6 pages.
"Notice of Allowance", U.S. Appl. No. 12/365,166, Apr. 16, 2010, 7 pages.
"Notice of Allowance", U.S. Appl. No. 12/365,166, Aug. 25, 2010, 4 pages.
"Notice of Allowance", U.S. Appl. No. 13/040,090, Mar. 8, 2012, 6 pages.
"Notice of Allowance", U.S. Appl. No. 13/088,237, Jun. 17, 2013, 8 pages.
"Notice of Allowance", U.S. Appl. No. 13/088,237, Jul. 11, 2013, 8 pages.
"Notice of Allowance", U.S. Appl. No. 13/188,419, May 22, 2013, 8 pages.
"Notice of Allowance", U.S. Appl. No. 13/924,838, Mar. 12, 2015, 7 pages.
"Notice of Allowance", U.S. Appl. No. 13/924,838, Jul. 8, 2015, 7 pages.
"On Extensions to Rel-8 PMI Feedback", 3GPP TSG RAN WG1 #60, R1-101129, Motorola, San Francisco, USA,, Feb. 2010, 4 pages.
"On OTDOA in LTE", 3GPP TSG RAN WG1 #55bis, Ljubljana, Slovenia; R1-090353, Jan. 2009, 8 pages.
"On OTDOA method for L TE Positioning", 3GPP TSG RAN WG1 #56, Ericsson, R1-090918, Athens, Greece, Feb. 2009, 6 pages.
"On Serving Cell Muting for OTDOA Measurements", 3GPP TSG RAN1 #57, R1-092628—Los Angeles, CA, USA, Jun. 2009, 7 pages.
"Performance evaluation of adaptive codebook as enhancement of 4 Tx feedback", 3GPP TSG RAN WG1#61bis, R1-103447, Jul. 2010, 6 pages.
"PHY Layer 1 1 4. Specification Impact of Positioning Improvements", 3GPP TSG RAN WG1 #56bis, Athens, Greece; Qualcomm Europe, R1-090852,, Feb. 2009, 3 pages.
"Physical Channels and Modulation (Release 8)", 3GPP TS 36.211 V8.6.0 (Mar. 2009) 3rd Generation Partnership Project; Technical Specification Group Radio Access 28 Network; Evolved Universal Terrestrial Radio Access (E-UTRA);, Mar. 2009, 83 pages.
"Physical Channels and Modulation (Release 9)", 3GPP TS 36.211 V9.0.0 (Dec. 2009); 3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA); Release 9, Dec. 2009, 85 pages.
"Physical layer procedures", 3GPP TS 36.213 V9.0.1 (Dec. 2009); 3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA); Release 9, Dec. 2009, 79 pages.
"Positioning Subframe Muting for OTDOA Measurements", 3GPP TSG RAN1 #58 R1-093406, Shenzhen, P. R. China, Aug. 2009, 9 pages.

"Positioning Support for L TE", 3GPP TSG RAN WG1 #42, Athens, Greece, RP-080995, Dec. 2008, 5 pages.
"Rationale for mandating simulation of 4Tx Widely-Spaced Cross-Polarized Antenna Configuration for LTE-Advanced MU-MIMO", 3GPP TSG-RAN WG1 Meeting #61bis, R1-104184, Dresden, Germany, Jun. 2010, 5 pages.
"Reference Signals for Low Interference Subframes in Downlink;", 3GPP TSG RAN WG1 Meeting #56bis; Seoul, South Korea; Ericsson; R1-091314, Mar. 2009, 8 pages.
"Signalling Support for PRS Muting in", 3GPP TSG RAN2 #70, Montreal, Canada; Ericsson, ST-Ericsson; R2-103102, May 2010, 2 pages.
"Some Results on DL-MIMO Enhancements for LTE-A", 3GPP TSG WG1 #55bis, R1-090328, Motorola; Ljubjana, Slovenia, Jan. 2009, 5 pages.
"Sounding RS Control Signaling for Closed Loop Antenna Selection", 3GPP TSG RAN #51, R1-080017—Mitsubishi Electric, Jan. 2008, 8 pages.
"Study on hearability of reference signals in LTE positioning support", 3GPP TSG RAN1 #56bisa—R1-091336, Seoul, South Korea, Mar. 2009, 8 pages.
"System Simulation Results for OTDOA", 3GPP TSG RAN WG4 #53, Jeju, South Korea, Ericsson, R4-094532;, Nov. 2009, 3 pages.
"Technical 1 34. Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA);", 3GPP TS 36.211 v8.4.0 (Sep. 2008); 3rd Generation Partnership Project; Physical Channels and Modulation (Release 8), 2008, 78 pages.
"Technical Specification Group Radio Access Network", 3GPP TS 25.305 V8.1.0 (Dec. 2008) 3rd Generation Partnership Project; Stage 2 functional specification of User Equipment (UE) positioning in UTRAN (Release 8), 2008, 79 pages.
"Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA)", 3GPP TS 36.305 V0.2.0 (May 2009) 3rd generation Partnership Project; Stage 2 functional specification of User Equipment, (UE) positioning in E-UTRAN (Release 9);, 2010, 52 pages.
"Text 1 3 0. proposal on Orthonogonal PRS transmissions in mixed CP deployments using MBSFN subframes", 3GPP TSG RAN WG1 #59, Jeju, South Korea, Motorola, R1-095003;, Nov. 2009, 4 pages.
"Text proposal on measurements", 3GPP TSG RAN2 #60bis, Tdoc R2-080420; Motorola, Sevilla, Spain, Jan. 2008, 9 pages.
"Two Component Feedback Design and Codebooks", 3GPP TSG RAN1 #61, R1-103328, Motorola, Montreal, Canada, May 2010, 7 pages.
"Two-Level Codebook design for MU MIMO enhancement", 3GPP TSG RAN WG1 #60, R1-102904, Montreal, Canada, May 2010, 8 pages.
"UTRAN SFN-SFN observed lime 11 difference measurement & 3GPP TS 25.311 IE 10.3.7.106 "UE positioning OTDOA neighbour cell info' assistance data D fields"", 3GPP TSG RAN WG4 (Radio) #20, New Jersey, USA; Tdoc R4-011408,, Nov. 2001, 4 pages.
"View on the feedback framework for Rei. 1 0", 3GPP TSG RAN WG1 #61, R1-103026, Samsung, Montreal, Canada, May 2010, 15 pages.
"Views on Codebook Design for Downlink 8Tx MIMO", 3GPP TSG RAN WG1 #60. R1-101219, San Francisco, USA, Feb. 2010, 9 pages.
Colin,"Restrictions on Autonomous Muting to Enable 1 58. Time Difference of Arrival Measurements", U.S. Appl. No. 61/295,678, filed Jan. 15, 2010, 26 pages.
Costas,"A Study of a Class of Detection Waveforms Having Nearly Ideal Range-Doppler Ambiguity Properties", Fellow, IEEE; Proceedings of the IEEE, vol. 72, No. 8, Aug. 1984, 14 pages.
Guey,"Synchronization Signal Design for OFDM Based on Time-Frequency Hopping Patterns", Ericsson Research; North Carolina, USA;, 2007, 6 pages.
Jafar,"On Optimality of Beamforming for Multiple Antenna Systems with Imperfect Feedback", Department of Electrical Engineering, Stanford University, CA, USA, 2004, 7 pages.
Knoppert,"Communication Device", U.S. Appl. No. 29/329,028, filed Dec. 8, 2008, 10 pages.
Knoppert,"Indicator Shelf for Portable Electronic Device", U.S. Appl. No. 12/480,289, filed Jun. 8, 2009, 15 pages.

(56) **References Cited**

OTHER PUBLICATIONS

Krishnamurthy,"Interference Control, SINR Optimization and Signaling Enhancements to Improve the Performance of OTDOA Measurements", U.S. Appl. No. 12/813,221, filed Jun. 10, 2010, 20 pages.

Krishnamurthy,"Threshold Determination in TDOA-Based Positioning System", U.S. Appl. No. 12/712,191, filed Feb. 24, 2010, 19 pages.

Sayana,"Method of Codebook Design and Precoder Feedback in Wireless Communication Systems", U.S. Appl. No. 61/374,241, filed Aug. 16, 2010, 40 pages.

Sayana,"Method of Precoder Information Feedback in Multi-Antenna Wireless Communication Systems", U.S. Appl. No. 61/331,818, filed May 5, 2010, 43 pages.

Visotsky,"Space—Time Transmit PrecodingWith Imperfect Feedback", IEEE Transactions on Information Theory, vol. 47, No. 6, Sep. 2001, pp. 2632-2639.

Zhuang,"Method for Precoding Based on Antenna Grouping", U.S. Appl. No. 12/899,211, filed Oct. 6, 2010, 26 pages.

"Advisory Action", U.S. Appl. No. 12/650,699, Jan. 30, 2013, 3 pages.

"Advisory Action", U.S. Appl. No. 12/650,699, Sep. 25, 2014, 3 pages.

"An-1432 the LM4935 Headset and Push-Button Detection Guide", Texas Instruments Incorporated—http://www.ti.com/lit/an/snaa024a.snaa024a.pdf, May 2013, 8 pages.

"Earbud with Push-to-Talk Microphone", Motorola, Inc., model 53727, iDEN 2.5 mm 4-pole mono PTT headset NNTNN5006BP, 2013, 10 pages.

"Final Improvement Proposal for PTT Support in HFP", Bluetooth SIG, Inc., revision V10r00 (PTTinHFP_FIPD), Jul. 20, 2010, 50 pages.

"Final Office Action", U.S. Appl. No. 12/650,699, Jul. 16, 2014, 20 pages.

"Final Office Action", U.S. Appl. No. 12/650,699, Jul. 29, 2015, 26 pages.

"Final Office Action", U.S. Appl. No. 12/650,699, Nov. 13, 2012, 17 pages.

"Final Office Action", U.S. Appl. No. 13/477,609, Jul. 31, 2015, 11 pages.

"Final Office Action", U.S. Appl. No. 13/721,771, Oct. 29, 2015, 8 pages.

"Final Office Action", U.S. Appl. No. 13/733,297, Jul. 22, 2015, 20 pages.

"Final Office Action", U.S. Appl. No. 13/873,557, Jul. 17, 2015, 13 pages.

"Final Office Action", U.S. Appl. No. 14/012,050, Jul. 6, 2015, 23 pages.

"Final Office Action", U.S. Appl. No. 14/052,903, Oct. 1, 2015, 10 pages.

"Final Office Action", U.S. Appl. No. 14/280,775, Dec. 9, 2015, 13 pages.

"Innovator in Electronics, Technical Update, Filters & Modules PRM Alignment", Module Business Unit, Apr. 2011, 95 pages.

"International Preliminary Report on Patentability", Application No. PCT/US2013/042042, Mar. 10, 2015, 8 pages.

"International Search Report and Written Opinion", Application No. PCT/US2014/060440, Feb. 5, 2015, 11 pages.

"International Search Report and Written Opinion", Application No. PCT/US2015/031328, Aug. 12, 2015, 11 pages.

"International Search Report and Written Opinion", Application No. PCT/US2014/045755, Oct. 23, 2014, 11 pages.

"International Search Report and Written Opinion", Application No. PCT/US2014/045956, Oct. 31, 2014, 11 pages.

"International Search Report and Written Opinion", Application No. PCT/US2014/056642, Dec. 9, 2014, 11 pages.

"International Search Report and Written Opinion", Application No. PCT/US2013/071615, Mar. 5, 2014, 13 pages.

"International Search Report and Written Opinion", Application No. PCT/US2013/040242, Oct. 4, 2013, 14 pages.

"International Search Report and Written Opinion", Application No. PCT/US2014/047233, Jan. 22, 2015, 8 pages.

"International Search Report and Written Opinion", Application No. PCT/US2013/077919, Apr. 24, 2014, 8 pages.

"International Search Report and Written Opinion", Application No. PCT/US2014/070925, May 11, 2015, 9 pages.

"International Search Report and Written Opinion", Application No. PCT/US2014/018564, Jun. 18, 2014, 11 pages.

"International Search Report and Written Opinion", Application No. PCT/US2013/072718, Jun. 18, 2014, 12 pages.

"International Search Report and Written Opinion", Application No. PCT/US2015/027872, Jul. 15, 2015, 12 pages.

"International Search Report", Application No. PCT/US20013/071616, Mar. 5, 2014, 2 pages.

"International Search Report", Application No. PCT/US2014/014375, Apr. 7, 2014, 4 pages.

"Market & Motivation (MRD Section3) for Interoperability Testing of Neighbor Awareness Networking", WiFi Alliance Neighbor Awareness Networking Marketing Task Group, Version 0.14, 2011, 18 pages.

"Marketing Statement of Work Neighbor Awareness Networking", Version 1.17, Neighbor Awareness Networking Task Group, May 2012, 18 pages.

"Motorola SJYN0505A Stereo Push to Talk Headset for Nextel", Motorola Inc., iDEN 5-pole 2.5 mm Stereo Headset SJYN05058A, 2010, 2 pages.

"Non-Final Office Action", U.S. Appl. No. 12/650,699, Mar. 30, 2015, 28 pages.

"Non-Final Office Action", U.S. Appl. No. 12/650,699, Apr. 23, 2013, 19 pages.

"Non-Final Office Action", U.S. Appl. No. 12/650,699, Jul. 19, 2012, 12 pages.

"Non-Final Office Action", U.S. Appl. No. 12/650,699, Dec. 16, 2013, 26 pages.

"Non-Final Office Action", U.S. Appl. No. 13/477,609, Dec. 3, 2014, 7 pages.

"Non-Final Office Action", U.S. Appl. No. 13/477,609, Dec. 14, 2015, 9 pages.

"Non-Final Office Action", U.S. Appl. No. 13/692,520, Sep. 5, 2014, 15 pages.

"Non-Final Office Action", U.S. Appl. No. 13/692,520, Oct. 5, 2015, 17 pages.

"Non-Final Office Action", U.S. Appl. No. 13/721,771, May 20, 2015, 6 pages.

"Non-Final Office Action", U.S. Appl. No. 13/733,297, Feb. 2, 2016, 17 pages.

"Non-Final Office Action", U.S. Appl. No. 13/733,297, Mar. 13, 2015, 23 pages.

"Non-Final Office Action", U.S. Appl. No. 13/873,557, Mar. 11, 2015, 19 pages.

"Non-Final Office Action", U.S. Appl. No. 13/945,968, Apr. 28, 2015, 16 pages.

"Non-Final Office Action", U.S. Appl. No. 13/955,723, Dec. 17, 2015, 21 pages.

"Non-Final Office Action", U.S. Appl. No. 14/012,050, Feb. 10, 2015, 18 pages.

"Non-Final Office Action", U.S. Appl. No. 14/031,739, Aug. 18, 2015, 16 pages.

"Non-Final Office Action", U.S. Appl. No. 14/052,903, Mar. 11, 2015, 7 pages.

"Non-Final Office Action", U.S. Appl. No. 14/068,309, Oct. 2, 2015, 14 pages.

"Non-Final Office Action", U.S. Appl. No. 14/150,047, Jun. 29, 2015, 11 pages.

"Non-Final Office Action", U.S. Appl. No. 14/226,041, Jun. 5, 2015, 8 pages.

"Non-Final Office Action", U.S. Appl. No. 14/280,775, 07/16/215, 9 pages.

"Non-Final Office Action", U.S. Appl. No. 14/330,317, Feb. 25, 2016, 14 pages.

"Non-Final Office Action", U.S. Appl. No. 14/339,476, Jan. 20, 2016, 9 pages.

(56)   **References Cited**

OTHER PUBLICATIONS

"Non-Final Office Action", U.S. Appl. No. 14/445,715, Jan. 15, 2016, 26 pages.

"Notice of Allowance", U.S. Appl. No. 12/650,699, Jan. 14, 2016, 8 pages.

"Notice of Allowance", U.S. Appl. No. 13/873,557, Dec. 23, 2015, 10 pages.

"Notice of Allowance", U.S. Appl. No. 13/945,968, Sep. 16, 2015, 6 pages.

"Notice of Allowance", U.S. Appl. No. 14/012,050, Dec. 14, 2015, 12 pages.

"Notice of Allowance", U.S. Appl. No. 14/052,903, Feb. 1, 2016, 8 pages.

"Notice of Allowance", U.S. Appl. No. 14/226,041, Dec. 31, 2015, 5 pages.

"Notice of Allowance", U.S. Appl. No. 14/488,709, Sep. 23, 2015, 10 pages.

"Pre-Brief Appeal Conference Decision", U.S. Appl. No. 12/650,699, Apr. 9, 2013, 2 pages.

"Restriction Requirement", U.S. Appl. No. 13/721,771, Mar. 16, 2015, 5 pages.

"Restriction Requirement", U.S. Appl. No. 14/031,739, Apr. 28, 2015, 7 pages.

"Supplemental Notice of Allowance", U.S. Appl. No. 14/488,709, Oct. 7, 2015, 8 pages.

Guo,"A Series-Shunt Symmetric Switch Makes Transmit-Receive Antennas Reconfigurable in Multipath Channels", IEEE 3d Int'l Conf. on Digital Object Identifier, May 29, 2011, pp. 468-471.

Li,"A Subband Feedback Controlled Generalized Sidelobe Canceller in Frequency Domain with Multi-Channel Postfilter", 2nd International Workshop on Intelligent Systems and Applications (ISA), IEEE, May 22, 2010, 4 pages.

MACCM"GaAs SP6T 2.5V High Power Switch Dual-/Tri-/Quad-Band GSM Applications", Rev. V1 data sheet, www.macomtech. com, Mar. 22, 2003, 5 pages.

Renesas,"uPG2417T6M GaAs Integrated Circuit SP6T Switch for NFC Application (R09DS0010EJ0100)", Rev. 1.00 data sheet, Dec. 24, 2010, 12 pages.

Tesoriero,"Improving Location Awareness in Indoor Spaces Using RFID Technology", Science Direct, Expert Systems with Applications, 2010, 894-898.

Valkonen,"Impedance Matching and Tuning of Non-Resonant Mobile Terminal Antennas", Aalto University Doctoral Dissertations, Mar. 15, 2013, 94 pages.

Vodafone"PDCCH Structure for MTC Enhanced Coverage", 3GPP TSG RAN WG1 #76, R1-141030, Prague, Czech Republic, Feb. 2014, 2 pages.

Yun,"Distributed Self-Pruning(DSP) Algorithm for Bridges in Clustered Ad Hoc Networks", Embedded Software and Systems; Lecture Notes in Computer Science, Springer, May 14, 2007, pp. 699-707.

Final Office Action, U.S. Appl. No. 14/150,047, Mar. 4, 2016, 14 pages.

Non-Final Office Action, U.S. Appl. No. 14/280,775, Mar. 23, 2016, 11 pages.

Notice of Allowance, U.S. Appl. No. 13/873,557, Apr. 11, 2016, 5 pages.

Notice of Allowance, U.S. Appl. No. 14/031,739, Mar. 1, 2016, 7 pages.

Supplemental Notice of Allowance, U.S. Appl. No. 14/031,739, Apr. 21, 2016, 2 pages.

* cited by examiner

FIG. 1

200

242   244

DEVICE   —240

205

210—   BASE STATION

FIG. 2

FIG. 3

FIG. 4

500

520

SECOND SUBSET OF
ANTENNAS AT BASE STATION

550

SECOND SUB-PRECODER
(LAYER-1)

560

SECOND SUB-PRECODER
(LAYER-2)

540

DEVICE

530

FIRST SUB-PRECODER
(LAYER-1)

540

FIRST SUB-PRECODER
(LAYER-2)

510

FIRST SUBSET OF ANTENNAS
AT BASE STATION

FIG. 5

_600_
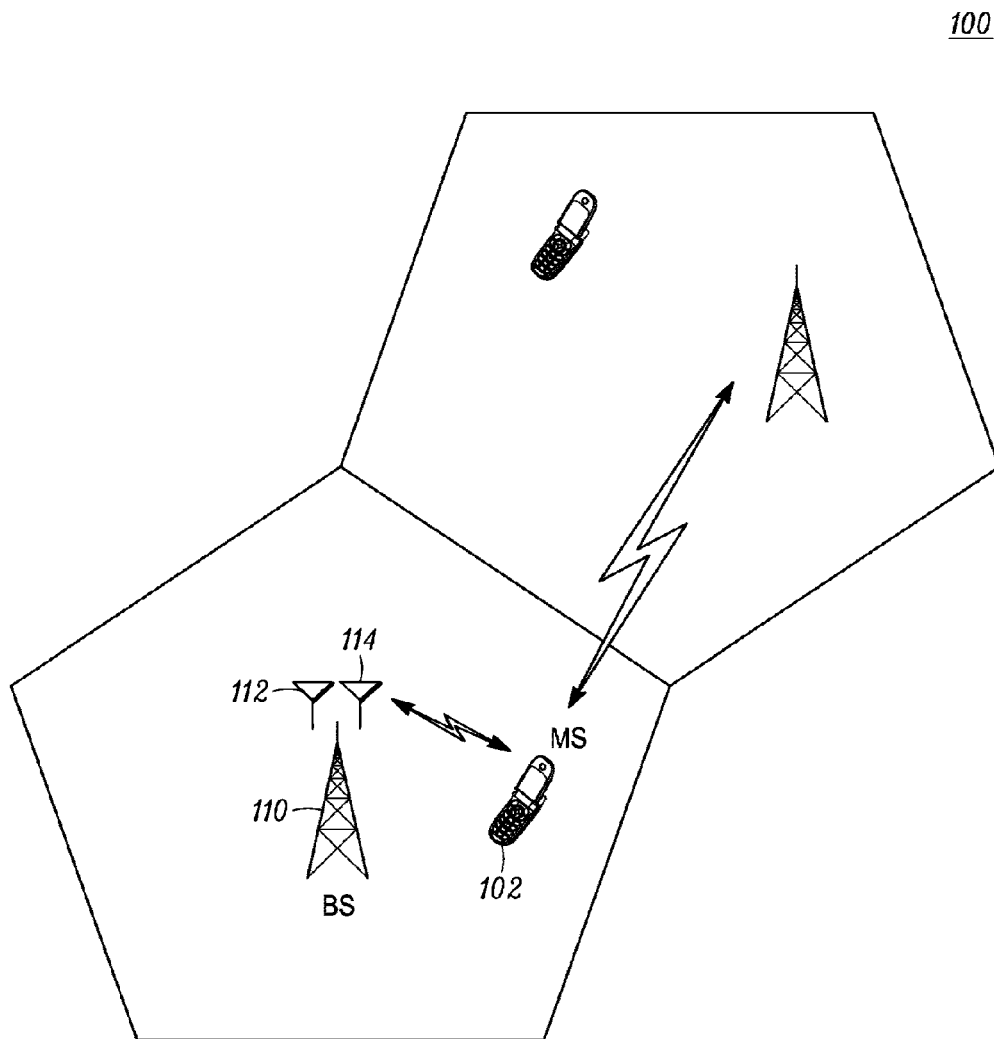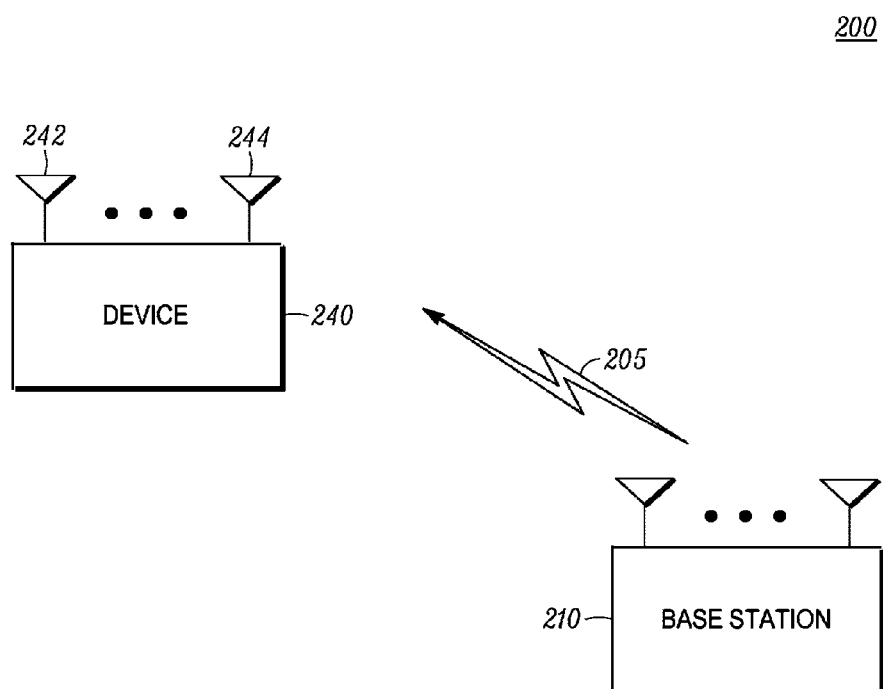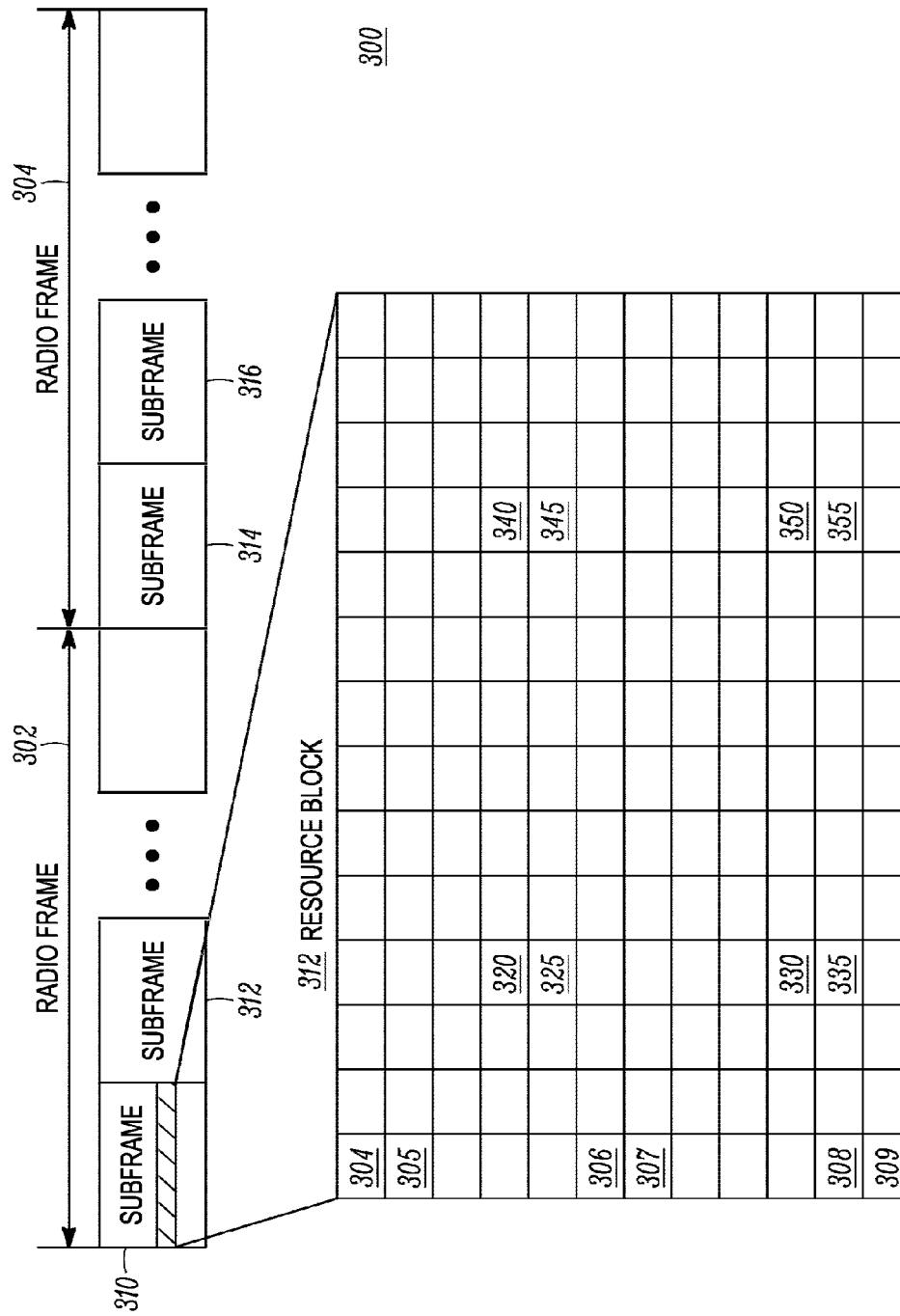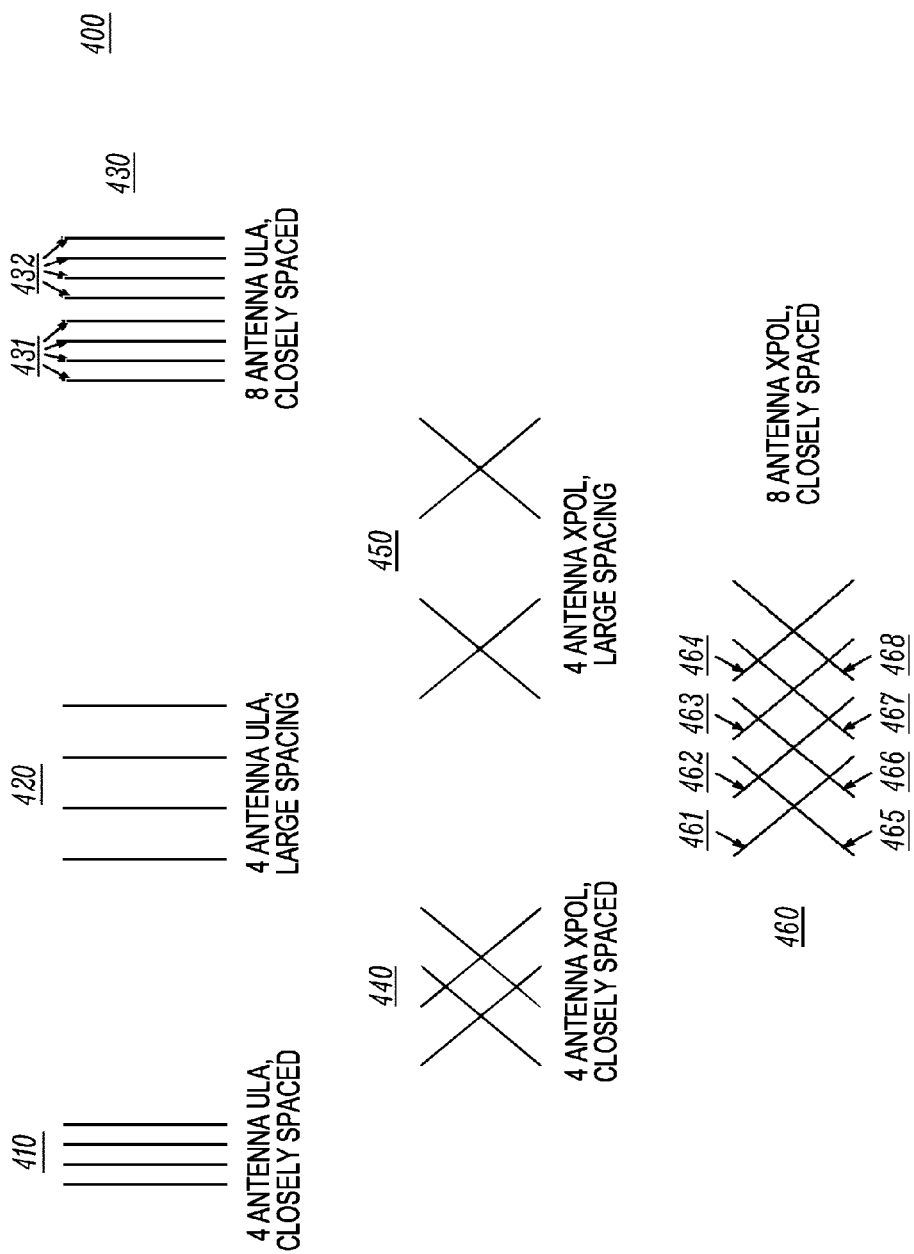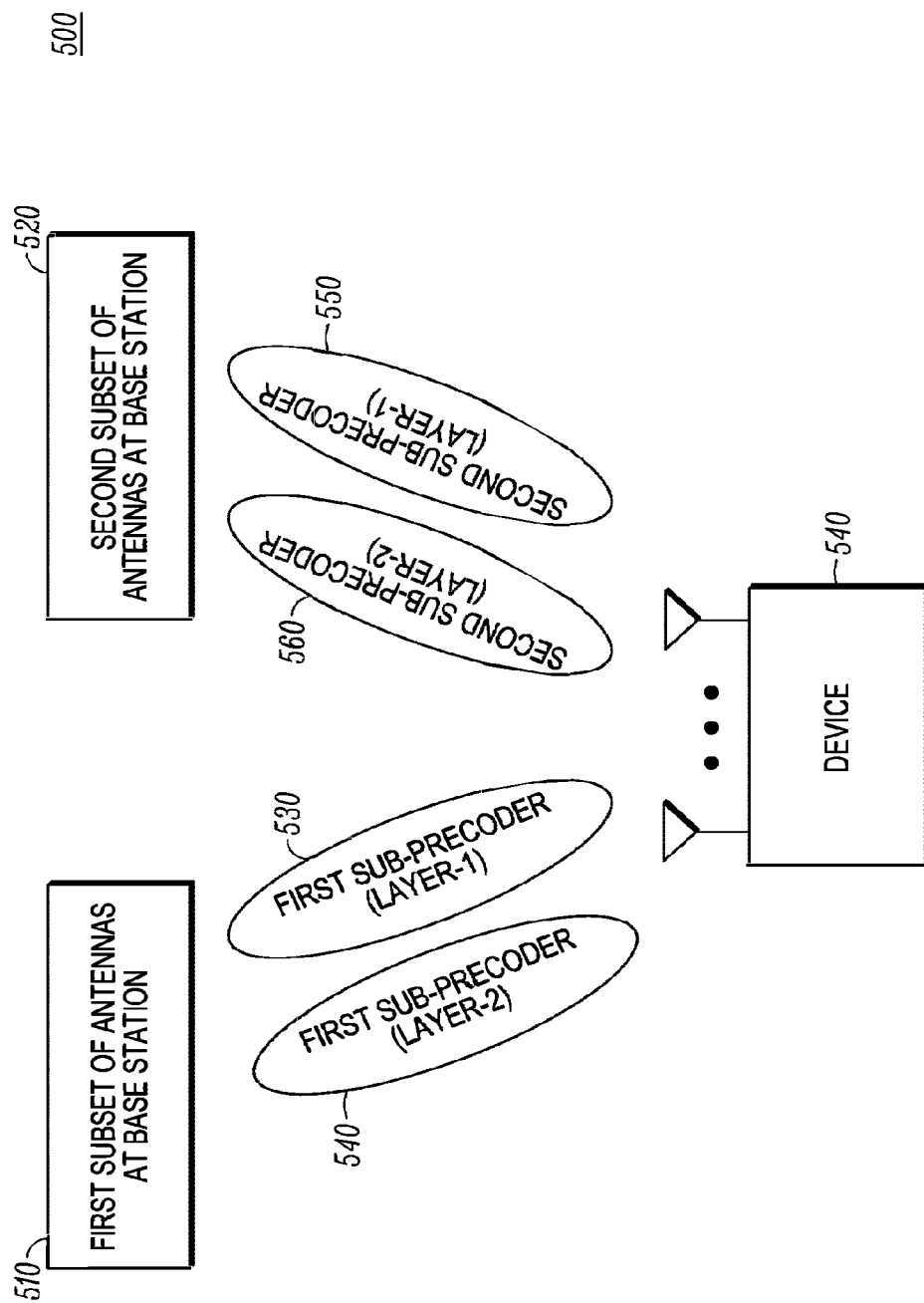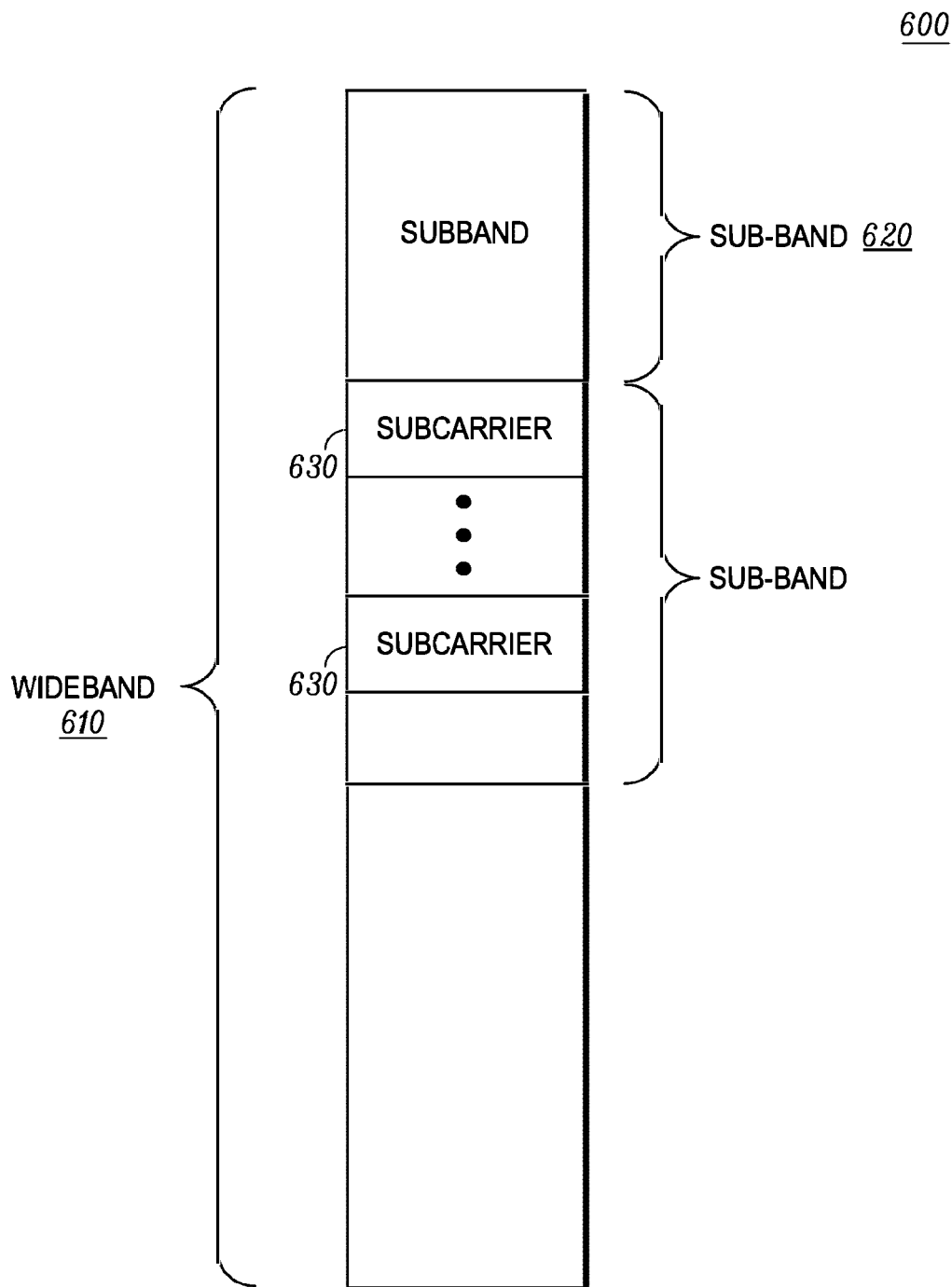
FIG. 6

METHOD AND PRECODER INFORMATION FEEDBACK IN MULTI-ANTENNA WIRELESS COMMUNICATION SYSTEMS

CROSS REFERENCE TO RELATED APPLICATIONS

The present application is a continuation application of U.S. patent application Ser. No. 13/924,838 filed on 24 Jun. 2013, that is a continuation of U.S. patent application Ser. No. 13/088,237 filed on 15 Apr. 2011, that claims priority to U.S. Provisional Patent Application No. 61/331,818 filed on 5 May 2010, the contents of all of which are incorporated herein by reference and from which benefits are claimed under 35 U.S.C. 119/120.

FIELD OF THE DISCLOSURE

The present disclosure relates generally to wireless communications and, more particularly, to a feedback framework in wireless communication systems.

BACKGROUND

In wireless communication systems, channel state information at a transmitter, for example, at a base station, is important for beam-forming transmissions (also referred to as precoding) that deliver more power to a targeted user while minimizing interference on other users. Precoding operations can be in the context of single-user multiple input multiple output (SU-MIMO) or multi-user MIMO (MU-MIMO), where two or more users are served by a single base station. An eNB needs accurate spatial channel information in order to perform a high rank transmission to a single UE or to perform precoding to two or more UEs simultaneously so that the mutual interference among multiple transmissions can be minimized at each UE.

Precoding operations may also be in the context of SU/MU-MIMO users served by coordinated multi-point (CoMP) transmissions where antennas belonging to different eNBs, rather than to the same eNB, can coordinate their precoding to serve multiple users simultaneously. Further support for up to eight transmit antennas is enabled in the next generation cellular standards like 3GPP LTE Release-10. Due to such a relatively large number of antennas (4-Tx or 8-Tx) involved in such transmissions, it is desirable that the UE feedback be designed efficiently with good performance overhead trade-off, so that feedback does not scale linearly with the increasing number of antennas.

The antenna configurations which support a large number of antennas in practice must allow large beamforming gains and also larger spatial multiplexing gains achieved from higher rank transmission. Beamforming allows efficient support for low geometry users and also for multi-user transmission thereby improving cell-edge and cell-average throughput with larger number of users in the system, while spatial multiplexing allows higher peak spectral efficiency. A typical antenna configuration to achieve this would be to have groups of antennas where each group is a set of correlated antennas and each group is uncorrelated with the other groups. A cross-polarized antenna configuration is one such setup. The correlated antenna elements provide the required beamforming gains and the uncorrelated antenna elements enable high rank transmissions.

The above structure in the antennas has some unique spatial characteristics that can be exploited. For example, the correlation among correlated antennas changes slowly and is

confined to a smaller vector space on an average. This can be used to feedback the correlated and uncorrelated channel characteristics, i.e., two components, at different rates and/or with different levels of quantization/overhead in time and frequency to reduce feedback overhead. One of the components representing the correlated channel characteristics can be fed back on a wideband basis and/or slowly in time, while the other component is fed back on a subband basis and/or more frequently in time.

However, one of the key challenges in designing such a two component feedback system is identifying the parameters used in the two components and the construction of the final precoder matrix as a function of the two components.

The various aspects, features and advantages of the invention will become more fully apparent to those having ordinary skill in the art upon a careful consideration of the following Detailed Description thereof with the accompanying drawings described below. The drawings may have been simplified for clarity and are not necessarily drawn to scale.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 illustrates a wireless communication system.

FIG. 2 illustrates an embodiment with a base station transmitting to a device.

FIG. 3 illustrates an example of a frame structure used in the 3GPP LTE Release-8 (Rel-8) specification and different reference symbols.

FIG. 4 illustrates exemplary antenna configurations at a base unit.

FIG. 5 illustrates a first subset of antennas and a second subset of antennas transmitting two spatial layers to a device.

FIG. 6 illustrates a wideband and subbands, each of which is further composed of contiguous subcarriers.

DETAILED DESCRIPTION

In FIG. 1, a wireless communication system 100 comprises one or more fixed base infrastructure units 110 and 120 forming a network distributed over a geographical region for serving remote units in the time and/or frequency domain. The base infrastructure unit may also be referred to as the transmitter, access point (AP), access terminal (AT), base, base station (BS), base unit (BU), Node-B (NB), enhanced Node-B (eNB), Home Node-B (HNB), Home eNB (HeNB) or by other terminology used in the art. The base units are generally part of a radio access network that includes one or more controllers communicably coupled to one or more corresponding base units. The access network is generally communicably coupled to one or more core networks, which may be coupled to other packet or data networks, like the Internet, and to public switched telephone networks (PSTN), among other networks. These and other elements of access and core networks are not illustrated but they are well known generally by those having ordinary skill in the art.

The one or more base units each comprise one or more transmitters for downlink transmissions and one or more receivers for receiving uplink transmissions from the remote units as described further below. The one or more base units serve a number of remote units, for example, remote unit 102 and 104 in FIG. 1, within a corresponding serving area, for example, a cell or a cell sector of the base unit, via a wireless communication link. The remote units may be fixed units or wireless communication devices. The remote unit may also be referred to as a receiver, subscriber station (SS), mobile, mobile station (MS), mobile terminal, user, terminals, user equipment (UE), user terminal (UT) or by other terminology

used in the art. The remote units also comprise one or more transmitters and one or more receivers. In FIG. 1, the base unit 110 transmits downlink communication signals to serve remote unit 102 in the time and/or frequency domain. The remote unit 102 communicates directly with base unit 110 via uplink communication signals.

The term "transmitter" is used herein to refer to a source of a transmission intended for receipt by a user or receiver. A transmitter may have multiple co-located antennas each of which emits, possibly different, waveforms based on the same information source. In FIG. 1, for example, antennas 112 and 114 are co-located. A transmitter is typically associated with a cell or a cell sector in the case of a base unit having or serving multiple sectors. Also, if a base unit has geographically separated antennas (i.e., distributed antennas with remote radio heads), the scenario is also referred to as "a transmitter". Thus generally one or more base units transmit information from multiple antennas for reception by a remote unit.

In the diagram 200 of FIG. 2, at 210, a base unit transmits from a plurality of antennas. Also in FIG. 2, a remote unit receives transmissions from a plurality of antennas, which may or may not be co-located. In a typical embodiment, a base unit may be associated with a cell-ID, by which it identifies itself to a remote unit. As a conventional mode of operation, also sometimes referred to as a single-point transmission scheme, a remote unit 240 receives transmissions from a plurality of antennas of a single base unit 210. Such a base unit is also referred to as a serving cell (or serving base unit) to the user device/remote unit.

In one implementation, the wireless communication system is compliant with the Third Generation Partnership Project (3GPP) Universal Mobile Telecommunications System (UMTS) Long Term Evolution protocol, also referred to as Evolved Universal Terrestrial Radio Access (EUTRA), or some future generation thereof, wherein the base unit transmits using an orthogonal frequency division multiplexing (OFDM) modulation scheme on the downlink and the user terminals transmit on the uplink using a single carrier frequency division multiple access (SC-FDMA) scheme. In another implementation, the wireless communication system is compliant with the IEEE 802.16 protocol or a future generation thereof. More generally, however, the wireless communication system may implement some other open or proprietary communication protocol where channel feedback is useful or desired. Thus the disclosure is not intended to be limited to or by the implementation of any particular wireless communication system architecture or protocol. The teachings herein are more generally applicable to any system or operation that utilizes multiple antennas in a transmission, whether the multiple antennas belong to a single base unit or to multiple base units or whether the multiple antennas are geographically co-located (e.g., belong to a single base unit) or distributed (belong to either remote radio heads or multiple cells).

In a general embodiment, pilots or reference symbols are sent from each antenna in a transmitter. These pilots occupy the operational bandwidth to allow users to estimate the channel state information (CSI) of the entire bandwidth. Typically the pilots from different antennas are orthogonal so the pilots do not interfere with each other. Such orthogonality can be ensured if the pilots are sent using different time and/or frequency resources or code resources. For example, in systems based on OFDM technology, the pilots can occupy different subcarriers in frequency or different OFDM symbols in time or share the same set of resources, but different code sequences.

In FIG. 3 illustrates a frame structure used in the 3GPP LTE Release-8 (Rel-8) protocol to illustrate a possible reference symbol (RS) pattern in an OFDM system. A subframe 310 in a radio frame 302 spans 14 OFDM symbols in time. Further a subframe 310 contains multiple resource blocks 312, each spanning 12 consecutive subcarriers in frequency. In typical OFDM based systems like 3GPP LTE, a block of consecutive OFDM symbols are referred to as a subframe. Each subcarrier location in each of the OFDM symbols is referred to as a resource element (RE), since a single data modulation symbol can be mapped to such a resource element. A resource block (RB) is defined as a block of REs comprising a set of consecutive sub-carrier locations in frequency and a set of symbols. In LTE Rel-8, a slot is defined to span 7 symbols and each subframe is made of two slots, and hence 14 symbols. A minimum resource unit allocated to a user is the two RBs corresponding to two slots in a subframe for a total of 2×12×7 REs. A resource block may be more generally defined as a set of resource elements/OFDM subcarrier resources in time and frequency domain.

Some of the REs in a RB are reserved for reference symbols (also referred to as pilots) to help in the demodulation and other measurements at the UE. These reference symbols, as defined in Release 8 specification of LTE can be further divided into two types. The first type is cell-specific reference symbols, which are cell-specific and "common" to all users, and are transmitted in all the RBs. A common reference symbol (CRS) may or may not correspond to actual physical antennas of the transmitter, but CRSs are associated with one or more antenna "ports", either physical or virtual. In FIG. 3, as an example only, RE 304, 305, 306, 307, 308 and 309 may be a CRS. The second type is user-specific or a dedicated reference symbol (DRS), which are user-specific and hence applicable only to that user, and allocated in the RB's allocated to that user's data. Furthermore, DRS typically correspond to "precoded" or beam-formed RSs, which can be directly used by a user for the demodulation of the data streams. The precoding operation is explained later. In FIG. 4, as an example only, RE 320, 325, 330, 335, 340, 345, 350 and 355 may be a DRS. In LTE Release-10, a new spare RS, namely CSI-RS are defined to enable channel measurements, while DRSs are primarily relied upon for demodulation. These can be used similar to CRSs in LTE Release-8 to derive channel feedback information.

The location of the reference symbols is known to the UE from higher layer configurations. For example, depending on the number of antenna ports as configured by a transmission unit, UE knows the location of all the reference symbols corresponding to all configured antenna ports. As another example, when a UE is instructed to use a DRS, the UE also knows the DRS locations, which may depend on the user identification.

In typical FDD operation of a LTE Rel-8 system, CRSs are used for both channel related measurements at the UE and also for demodulation. If eNB employs a precoder at the transmitter, such information is made available to the UE, which allows it to construct the channel for demodulation based on the CRSs. In a FDD operation of a future LTE Rel-10 system, CSI-RS (and possibly CRSs that may still be available) may be used for channel related measurements, while DRSs are used for demodulation. Hence an eNB may apply precoder which are not exactly the same as the UE feedback, and does not have to signal the precoder explicitly. This is further described in detail later.

The "precoding" operation is explained in the following. The base station transmits a signal via weighting each

antenna signal with a complex value, an operation referred to as precoding, which may be mathematically represented by the matrix equation:

$$Y = HVs + n$$

in which, when transmitting one spatial layer of data, or rank-1, may be represented as:

$$\begin{bmatrix} y_1 \\ \vdots \\ y_{N_R} \end{bmatrix} = \begin{bmatrix} h_{1,1} & \cdots & h_{1,N_T} \\ \vdots & \ddots & \vdots \\ h_{N_R,1} & \cdots & h_{N_R,N_T} \end{bmatrix} \begin{bmatrix} v_1 \\ \vdots \\ v_{N_T} \end{bmatrix} s + n$$

in which, when transmitting two spatial layers of data, or rank-2, may be represented as:

$$\begin{bmatrix} y_1 \\ \vdots \\ y_{N_R} \end{bmatrix} = \begin{bmatrix} h_{1,1} & \cdots & h_{1,N_T} \\ \vdots & \ddots & \vdots \\ h_{N_R,1} & \cdots & h_{N_R,N_T} \end{bmatrix} \begin{bmatrix} v_{1,1} & v_{1,2} \\ \vdots & \vdots \\ v_{N_T,1} & v_{N_T,2} \end{bmatrix} \begin{bmatrix} s_1 \\ s_2 \end{bmatrix} + n$$

where $y_1 \ldots y_{N_R}$ may be the received data at the UE receive antenna #1 to #N_R, respectively. In the example with a rank-1 transmission, or a transmission with one data stream denoted as "s", the Matrix V may be a precoding vector with weights $v_{1,1} \ldots v_{N_T,1}$ for base station transmit antenna #1 to #N_T respectively. In an embodiment with a rank-2 transmission, or a transmission with two data streams s1 and s2 on the same subcarrier, V may be a precoding matrix. Precoding vector and precoding matrix can be referred to as precoding matrix given vector is a degenerated case of matrix.

Matrix H may be the propagation channel matrix between transmit antennas and receive antennas with entry h_{ij} representing a channel between the jth transmit and ith receive antennas. Value n may represent noise and interference. The precoding weights V, either a vector or matrix, may be determined by the base station, typically based on the channel particular to the UE or can be UE-specific and may also take into account a preference indicated by feedback from the UE. Further the matrix HV can be referred to as the effective channel between a user's data streams and its receivers. The effective channel, instead of the propagation channel H, is all a UE needs for demodulation purposes. The precoding weights may or may not be constrained to a predefined codebook that consists of a set of pre-defined vectors or matrices. In an embodiment with constrained precoding, the precoding matrix may be signaled by the base unit efficiently with a precoding matrix index (PMI) or with an index to a precoding matrix within a predefined codebook. The term "matrix" in this context may include the degenerated special case of vector, which applies to single stream transmission. In the most generic sense, the term "precoding" refers to any possible transmission scheme that may be deemed as mapping a set of data streams to an antenna set using a matrix V.

The applied precoding could be based on corresponding feedback from the UE or channel measurements at a base station. In a simple single-user single base unit scheme, one set of DRSs could be defined corresponding to the effective precoded channel (i.e., "HV" in the above equation). If two streams are transmitted to a user in a rank-2 transmission, then only 2 DRS ports (i.e., 2 subsets of DRS each corresponding to a precoded antenna port) are sufficient, even though the actual signal transmission may come from all the N_T antennas at the base unit where N_T can be greater than 2. In FIG. **3**, as an example only, RE **320**, **340**, **330** and **350** may

correspond to one DRS port while RE **325**, **345**, **335** and **355** may correspond to another DRS port.

In a future migration of a system, for example in 3GPP LTE Release 10 and beyond, user-specific RS (or DRS) are expected to be used widely with advanced Multiple-Input Multiple-Output (MIMO) modes like Coordinated Multi-point transmission (CoMP) and multi-user (MU) MIMO modes described earlier. As described earlier, DRSs are sufficient to enable demodulation. This is also helpful since an eNB is not required to signal exact transmission parameters like precoders, co-ordinating points, etc. However, an estimate of the actual (un-precoded or explicit) channel is required at the eNB to derive such transmission parameters. So as mentioned before, feedback measurements for this purpose are enabled in LTE Release-10 by defining lower density reference signals specifically for the purpose of feedback measurements (CSI-RS). Since they do not need to support demodulation, like CRS in LTE Release 8, a lower density is sufficient. Further, with CoMP, CSI-RS may be setup to enable measurements at the user device on a plurality of antennas from multiple base units. In FIG. **3**, as an example only, RE **304**, **305**, **306**, **307**, **308** and **309** may also be CSI-RS.

From either CRS or CSI-RS, the remote unit receiver can estimate the CSI. For the OFDM example, the receiver estimates CSI at each subcarrier between each receiver antenna and each transmitter antenna. The CSI may be denoted as a channel matrix on a sub-carrier k represented by

$$H_k = \begin{bmatrix} h_{11} & h_{12} & \cdots & h_{1Nt} \\ h_{21} & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots \\ h_{Nr1} & \cdots & \cdots & h_{NrNt} \end{bmatrix}$$

where h_{ij} is the channel matrix from jth transmit antenna to the ith receive antenna.

A correlation between antenna port i and antenna port j may be computed as follows

$$R = \frac{1}{|S|} \sum_{k \in S} h_{ki}^* h_{kj}$$

where h_{ki} is the channel measured corresponding to antenna port i on subcarrier k, S is a set of subcarriers, typically corresponding to the whole operational bandwidth (denoted as R_{WB}) or a sub-band/narrowband (denoted as R_{NB}).

More generally, an antenna correlation matrix that represents the spatial covariance among a plurality of transmit antennas can be computed as follows

$$R = \frac{1}{|S|} \sum_{k \in S} H_k^H H_k = \begin{bmatrix} R_{11} & \cdots & \cdots & R_{1,Nt} \\ \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots \\ R_{Nt,1} & \cdots & \cdots & R_{Nt,Nt} \end{bmatrix}$$

The Eigen Decomposition of R may be expressed in a well-defined format as

$$VDV^H \quad (1)$$

where V is a unitary matrix of Eigen vectors, where the first column is the most dominant vector, the second column the

second dominant vector and so on. D is a diagonal matrix with diagonal entries as Eigen values of R. The full knowledge of R at the transmitter will enable advanced beamforming/precoding techniques that will improve spectral efficiency and system throughput. However, the overhead may be large and approximations suitable to the transmission mode are applied.

For SU-MIMO precoding, the Eigen space information as represented by V above can be viewed as optimal precoding transmission weights in a capacity maximizing sense.

Existing 4th Generation (4G) air interfaces (i.e., 3GPP LTE and IEEE 802.16e) already support beamforming operation via the precoding operation as described earlier. To support precoding operation from the base station, a user terminal will be reporting back to the base station a preferred Precoding Matrix Index (PMI) which is an index to a set of predetermined precoding matrices. The recommended precoding matrix is obtained at the user terminal based on a certain metric such as maximizing the post-precoding link quality or throughput and is selected from one of the quantized codebook entries, wherein the codebook is known to the transmitter and the receiver. Specifically, the standard requires the UE to feedback the PMI that supports a MCS (modulation and coding scheme) with the highest rate, while satisfying a probability if block error target. In future releases, different or more explicit definitions of PMI may be defined. However, in general, the preferred PMI approximately represents a vector quantization of the dominant Eigenspace of R. Further PMI is feedback with an associated rank and as such PMI is an quantized approximation of V(1:r), where 'r' is the rank.

FIG. 4 illustrates some exemplary antenna configurations at a base unit. A closely spaced ULA, with a typical spacing of 0.5 to 1 wavelengths, is illustrated in 410. A large spaced ULA with typical spacing of 4 to 10 wavelengths is illustrated in 420. A cross-polarized configuration with two sets of cross-poles each with two antennas at +/−45 polarizations is illustrated in 440. Depending on the configuration, the correlation between different antenna elements may have a certain structure. Some exemplary cases are described herein.

We now illustrate how the structure of the antenna configuration can be used to develop efficient precoder structures.

One of the structures that can be exploited is a Kronecker based approximation of the channel covariance. For example, an 8×8 long term covariance matrix corresponding to 8 antennas, as in FIG. 4 at 460, for the transmitter can be approximated as a Kronecker product of a 4×4 correlation matrix corresponding to the ULA and a 2×2 correlation matrix, corresponding to the cross-polarized component i.e.,

$$R = R_{XPOL} \otimes R_{ULA}$$

Conceptually, the ULA Kronecker component R_{ULA} captures the correlation submatrix between two non-overlapping subsets of antennas with similar ULA configuration, which in FIG. 4 at 460 are antenna sets (461-464) and (465-468). The polarization Kronecker component R_{Pol} captures the correlation submatrix between subsets with similar cross-polarized configuration, namely antenna subsets (461,465), (462,466), (463,467) and (464,468) in FIG. 4. More generally, the spacing/location and polarization of antenna elements introduce some redundant structure in the antenna correlation, which lead to good Kronecker approximations and can be used as effective compression schemes for feedback overhead reduction. The above representation in the covariance matrix also translates to similar structure for the precoder.

Even for ULA, the transmit antennas can also be divided into two non-overlapping subsets of antennas. An example is shown in FIG. 4 for subset 431 and 432.

The final precoder for SU-MIMO rank-r may be computed as

$$V = SVD(R_{XPOL,b} \otimes R_{ULA,WB}) \tag{0.2}$$

The principal Eigen vectors and Eigen values of the constructed matrix are related to that of the Kronecker components as

$$D = \text{permute}(D_{XP} \otimes D_{ULA})$$

$$V = \text{permute}(V_{XP} \otimes V_{ULA}) \tag{0.3}$$

where the "permute" operation performs re-ordering of Eigen values.

We can further illustrate how the reordering influences the structure of the precoder for a 4 Tx cross-pole as an example, where both the ULA and cross-pole sub-matrices are of size 2×2, i.e.,

$$R_{ULA} = [v_{ula,1}, v_{ula,2}] \begin{bmatrix} \lambda_1 & 0 \\ 0 & \lambda_2 \end{bmatrix} [v_{ula,1}, v_{ula,2}]^H \tag{0.4}$$

$$R_{XP} = [v_{xp,1}, v_{xp,2}] \begin{bmatrix} \kappa_1 & 0 \\ 0 & \kappa_2 \end{bmatrix} [v_{xp,1}, v_{xp,2}]^H \tag{0.5}$$

Let us consider a rank-2 SU-MIMO transmission as a further example. Typically the cross-pole covariance matrix is highly rank-2 and ULA covariance can be approximated as rank 1. To express it quantitatively, if the two Eigen values ratios satisfy

$$\frac{\lambda_1}{\lambda_2} > \frac{\kappa_1}{\kappa_2},$$

then the rank-2 SU-MIMO precoder, after corresponding re-ordering, can be approximated as

$$[v_{xp,1} \quad v_{xp,2}] \otimes v_{ula,1} = \begin{bmatrix} v_{ula,1}v_{xp,11} & v_{ula,1}v_{xp,21} \\ v_{ula,1}v_{xp,12} & v_{ula,1}v_{xp,22} \end{bmatrix} \tag{0.6}$$

On the other hand, in case of

$$\frac{\lambda_1}{\lambda_2} < \frac{\kappa_1}{\kappa_2}$$

(which is less likely but could occur on short-term basis, like a subband of contiguous subcarriers), then the rank-2 precoder may be approximated as

$$[v_{xp,1}] \otimes [v_{ula,1} \quad v_{ula,2}] = \begin{bmatrix} v_{ula,1}v_{xp,11} & v_{ula,2}v_{xp,11} \\ v_{ula,1}v_{xp,12} & v_{ula,2}v_{xp,12} \end{bmatrix} \tag{0.7}$$

As can be seen, two structures are shown which allow expressing the overall precoder as a Kronecker product of two precoders. Further, the ULA component of the precoder may be feedback at a different time/frequency granularity than the cross-pole component of the precoder, and allows two component feedback schemes.

Though the Kronecker representation leads to an elegant separation to two component precoders and is one way to achieve two-component feedback, it also imposes some limitations, where either the ULA or the cross-pol component is assumed to be rank 1 for deriving an overall rank-2 precoder. In general, however a more general two-component precoder structure is useful for higher ranks, which will be further discussed below.

For the purpose of discussion, we will assume the long-term/correlated component corresponds to a wide frequency band such as the whole system bandwidth and the short-tem component corresponds to a subband/narrowband that is composed of a set of contiguous subcarriers and is a part of the wideband.

The optimal precoding vector V (optimal in an information theoretic capacity maximizing sense) can be obtained from the Eigen decomposition of the narrowband covariance matrix for band indexed 'b' as follows.

$$R_{NB,b} = V_{NB,b} D_{NB,b} V_{NB,b}{}^H \qquad (0.8)$$

For the rank-2 or 2-layer precoder, the ideal precoder is simply the first two columns of $V_{NB,b}$. Let us denote the rank-2 Eigen decomposition based precoder as follows (a partition based representation of $V_{NB,b}$)

$$\begin{bmatrix} v_{11} & v_{12} \\ v_{21} & v_{22} \end{bmatrix} \qquad (0.9)$$

where v_{ij} is a 4×1 (assuming 8-Tx eNB) vector. Clearly, each block corresponds to a vector of weights applied on a subset of antennas (e.g., ULA subset) corresponding to one spatial layer of data stream.

In a preferred embodiment, we approximate or otherwise represent $V_{NB,b}$ as

$$\begin{bmatrix} v_{11}\gamma_{11} & v_{12}\gamma_{12} \\ v_{21}\gamma_{21}e^{j\theta_1} & v_{22}\gamma_{22}e^{j\theta_2} \end{bmatrix} \qquad (0.10)$$

and then we can impose the constraint $\|v_{11}\|=\|v_{12}\|=\|v_{21}\|=\|v_{22}\|=1$ and γ_{ij} are real values and $\theta_1,\theta_2 \in [0, 2\pi]$.

Clearly, the above precoder representation is based on a matrix with a block of sub-matrices, where each sub-matrix is represented with a vector multiplied with a scalar. More importantly, each sub-matrix corresponds to transmission from a subgroup of antennas, and as one special case, where they all have the same polarization.

FIG. 5 further describes the above precoding operation from two subsets of antennas. Two non-overlapping subsets of antennas 510, 520 are weighted by a first and a second sub-precoder matrix, respectively. Each sub-precoder matrix corresponds to one or more spatial layers of data transmission, for example in FIG. 5, the first sub-precoder is for spatial layer 1 (530) and layer-2 (540). Similarly for the second-precoder, it corresponds to two spatial layers. Mathematically, as an example with eight antennas composed of two groups of 4 antennas, where the first subgroup is number 1-4, and second subgroup numbered 5-8, a rank r precoder may be expressed as follows

$$\begin{bmatrix} v_{11} & v_{12} & \cdots & v_{1r} \\ v_{21} & \cdots & \cdots & \cdots \\ v_{31} & \cdots & \cdots & \cdots \\ v_{41} & \cdots & \cdots & v_{4r} \\ v_{51} & v_{52} & \cdots & v_{5r} \\ v_{61} & \cdots & \cdots & \\ v_{71} & \cdots & \cdots & \cdots \\ v_{81} & \cdots & \cdots & v_{8r} \end{bmatrix} \qquad (11)$$

In the above the first sub-precoder is the top 4 rows (1-4) and the second sub-precoder is the bottom 4 rows (5-8)

A precoder matrix of one or more vectors associated with one or more spatial layers consists of a first sub-precoder matrix, which comprises of a first set of weights on a first subsets of transmit antennas of the base station, and a second sub-precoder matrix which comprises of a second set of weights on a second subset of transmit antennas of the base station as illustrated above. The set of weights here can be for one or more spatial layers of transmission.

In the final precoder matrix, the first sub-precoder matrix is one or more column vectors, which are of length equal to the number of antennas in the first subgroup, multiplied by one or more scalars. Similarly for the second sub-precoder.

For practical reasons, it is often preferred to have the precoder satisfy two constraints, namely i) Full power utilization on each transmit antenna, for maximum Power Amplifier (PA) use and ii) Equal power on each transmitted stream. These constraints can be imposed on the precoder structure $V_{NB,b}$. To satisfy equal power constraint on each transmit stream, we can impose additional constraint of $\gamma_{11}+\gamma_{21}=\gamma_{12}+\gamma_{22}$. To satisfy full power utilization on each individual transmit antenna, we could impose as a sufficient condition, that $\gamma_{11}+\gamma_{12}=\gamma_{21}+\gamma_{22}$ and that v_{ij} are constant modulus vectors. With these constraints, we have another preferred embodiment of the precoder structure as follows,

$$\begin{bmatrix} v_{11}\rho & v_{12}\sqrt{1-\rho^2} \\ v_{21}\sqrt{1-\rho^2}\,e^{j\theta_1} & v_{22}\rho e^{j\theta_2} \end{bmatrix},$$

$$\theta_1, \theta_2 \in [0, 2\pi], \rho^2 \in [0, 1]$$

The above discussion on the precoder structure is tied to feedback method in this invention. In the feedback scheme for a wireless communication device to send a precoder matrix information to a base station, the wireless communication device sends a first representation of a first matrix chosen from a first codebook, wherein the first matrix has at least two column vectors. The wireless communication device sends a second representation of a second matrix chosen from a second codebook, wherein the first representation and the second representation together convey a precoder matrix of one or more vectors associated with one or more spatial layers. The precoder matrix comprises a first sub-precoder matrix including a first set of weights on a first subsets of transmit antennas of the base station and a second sub-precoder matrix including a second set of weights on a second subset of transmit antennas of the base station. The first sub-precoder matrix is one or more column vectors of the first matrix corresponding to the first representation, multiplied by one or more entries of the second matrix corresponding to the second representation, and the second sub-precoder matrix is one ore more column vectors of the first matrix corresponding to the first representation, multiplied by one or more entries of the second matrix corresponding to the second representation.

The two-component feedback conveys the information of a precoder matrix recommended by the user to the base station. The actual precoder used by the base station may be different from the suggested precoder, but the actual precoder is derived from the recommended feedback.

We can use the embodiment above to describe a particular example here. A user feeds back a representation of a first chosen matrix that has a set of vectors v_{11}, v_{12}, v_{21}, v_{22}, wherein the representation can be just the index of the chosen

matrix within a codebook. Then, the user feeds back a representation of a second matrix of the form of

$$\begin{bmatrix} \rho & \sqrt{1-\rho^2} \\ \sqrt{1-\rho^2}\, e^{j\theta_1} & \rho e^{j\theta_2} \end{bmatrix},$$

also as index within a codebook format. The precoder information conveyed by these two representations corresponds to a final precoder matrix defined by

$$W = \begin{bmatrix} v_{11}\rho & v_{12}\sqrt{1-\rho^2} \\ v_{21}\sqrt{1-\rho^2}\, e^{j\theta_1} & v_{22}\rho e^{j\theta_2} \end{bmatrix}.$$

In one embodiment, the vector v_{ij} could be selected from a constant modulus codebook. One embodiment is a codebook of DFT vectors described below. Alternatively, one could consider a codebook expanded to include some non-DFT vectors.

A DFT codebook can be described as

$$v_{ij} \in \left\{ \begin{bmatrix} 1 & e^{\frac{2\pi jn}{N_1}} & e^{\frac{2\pi j.2n}{N_1}} & \dots & e^{\frac{2\pi j.Ln}{N_1}} \end{bmatrix}^T, n = 0, 1, \dots N_1 = 2^{B_1} - 1 \right\},$$

which requires B1 bits for representation. L could be Nt/2 for the cross-pole configuration described.

Further, each column of the second matrix can be considered as a co-phasing vector that aligns the phase of the transmission using the first sub-precoder and the second sub-precoder. In the case of $\rho^2=0.5$ which results in the same amplitude of the entries of the second matrix, we can define another codebook from which the co-phasing vectors are allowed to choose, and an example of the co-phasing codebook is

$$[1 \ e^{j\theta_i}] \in \left\{ \begin{bmatrix} 1 & e^{\frac{2\pi jn}{N_2}} \end{bmatrix}^T, n = 0, 1, \dots N_2 = 2^{B_2} - 1 \right\},$$

with B2 bits of representation.

More importantly, the above structure can also take advantage of wideband properties. For example, one can observe that v_{ij} are constrained in vector space to a set of entries in the codebook that are highly related to the Eigen space of the ULA component (more specifically the covariance matrix R_{ULA} among the correlated antennas). Similarly the amplitude factor ρ is also related to the Eigen Spread λ_1/λ_2. The co-phasing is expected to change more on a subband basis as it relates to the phase alignment between cross-pol groups of antennas.

A preferred embodiment of implementation of two-component feedback is described by adapting $v_{11}, v_{12}, v_{21}, v_{22}$. The general adaptation can take the following steps of i) Feedback of a set of vectors $\{v_{11}{}^{wb}, v_{12}{}^{wb}, v_{21}{}^{wb}, v_{22}\}$ in the form of codebook entries on a wideband basis, and ii) Feed back a representation of a rotation matrix ω_{ij} to rotate the wideband vector to arrive at the subband vector (i.e., subprecoder vector that is suitable for the particular sub-band of interest). The rotation matrix is also in the form of a codebook and is typically smaller in size. The co-phasing and the amplitude scalar ρ are feedback on a subband basis.

An exemplary embodiment is further described below, where a DFT codebook is used for the wideband vectors and an oversampled DFT based codebook is used for the rotation codebook. As a special case, K can be set to one.

$$v_{ij}^{wb} \in \left\{ \begin{bmatrix} 1 & e^{\frac{2\pi jn}{N_1}} & e^{\frac{2\pi j.2n}{N_1}} & \dots & e^{\frac{2\pi j.Ln}{N_1}} \end{bmatrix}^T, n = 0, 1, \dots N_1 = 2^{B_1} - 1 \right\}$$

$$v_{ij}^{nb} = \omega_{ij} v_{ij}^{wb}$$

$$\omega_{ij} \in CB_{ij} = \left\{ \operatorname{diag}\!\left(\begin{bmatrix} 1 & e^{\frac{2\pi jn}{N_1K}} & e^{\frac{2\pi j.2n}{N_1K}} & \dots & e^{\frac{2\pi j.Ln}{N_1K}} \end{bmatrix}^T \right), \right.$$

$$\left. n = -2^{B_2-1} = -N_2/2, -(N_2/2-1), \dots 0\dots, N_2/2-1 \right\}$$

Another alternate representation of the above is

$$v_{ij}^{wb} \in \left\{ \begin{bmatrix} 1 & e^{\frac{2\pi jn}{N_1}} & e^{\frac{2\pi j.2n}{N_1}} & \dots & e^{\frac{2\pi j.Ln}{N_1}} \end{bmatrix}^T, n = 0, 1, \dots N_1 = 2^{B_1} - 1 \right\}$$

$$v_{ij}^{nb} = \operatorname{diag}(v_{ij}^{wb})\omega_{ij}$$

$$\omega_{ij} \in CB_{ij} = \left\{ \left(\begin{bmatrix} 1 & e^{\frac{2\pi jn}{N_1K}} & e^{\frac{2\pi j.2n}{N_1K}} & \dots & e^{\frac{2\pi j.Ln}{N_1K}} \end{bmatrix}^T \right), \right.$$

$$\left. n = -2^{B_2-1} = -N_2/2, -(N_2/2-1), \dots 0\dots, N_2/2-1 \right\}$$

In a variation of the above embodiment, the codebook for the wideband vectors and/or rotation matrix may include some non-DFT vectors in addition to DFT vectors.

In a more general embodiment, the rotation codebook may also be further defined dependent on the original codebook entry or a combination of dependent and independent entries. Note that above embodiment uses an independent and fixed codebook.

The main objective of the above representation is to use more feedback bits to capture the wideband information and used fewer bits to capture subband information. An exemplary embodiment is to use a 2 bit codebook for subband vectors and a 4 or 6 bit codebook to represent the wideband entries. In general, the selection of (B_1, B_2) may depend on the feedback mode. More specifically, it could depend on the number of sub-bands the feedback is requested on.

As a further refinement of the above embodiments, we can further reduce the number of wideband vectors to two from 4, which are then represented as $(v_1{}^{wb}, v_2{}^{wb})$ for rank-2. Reducing the wideband basis vectors from 4 in the most generic case to 2 is based on the observation that the spatial correlation of the ULA sub-array can be approximated well by the first two dominant eigenvectors in general and is sufficient for rank 2.

We describe another preferred representation of precoder based on above simplifications, which is based on the steps 1) a user feeds back a representation of a first chosen matrix $(v_1{}^{wb}, v_2{}^{wb})$ which could be seen as representing the wideband property of the ULA sub-array; and 2) the user may optionally adapt $(v_1{}^{wb}, v_2{}^{wb})$ on a subband basis with a rotation codebook CB_i, as $v_{nb}{}^i = f(v_{wb}{}^i, CB_i)$; 3) the user feeds back a representation of a second matrix of the form of

$$\begin{bmatrix} \rho & \sqrt{1-\rho^2} \\ \sqrt{1-\rho^2}\, e^{j\theta_1} & \rho e^{j\theta_2} \end{bmatrix},$$

also as index within a codebook format. The precoder information conveyed by these two representations corresponds to

a final precoder matrix defined by one of the three structures below (the user is allowed to select which structure to use)

$$\begin{bmatrix} v_{nb}^1 \rho & v_{nb}^1 \sqrt{1-\rho^2} \\ v_{nb}^1 \sqrt{1-\rho^2}\, e^{j\theta_1} & v_{nb}^1 \rho e^{j\theta_2} \end{bmatrix}$$

$$\begin{bmatrix} v_{nb}^1 \rho & v_{nb}^2 \sqrt{1-\rho^2} \\ v_{nb}^1 \sqrt{1-\rho^2}\, e^{j\theta_1} & v_{nb}^2 \rho e^{j\theta_2} \end{bmatrix}$$

$$\begin{bmatrix} v_{nb}^1 \rho & v_{nb}^2 \sqrt{1-\rho^2} \\ v_{nb}^2 \sqrt{1-\rho^2}\, e^{j\theta_1} & v_{nb}^1 \rho e^{j\theta_2} \end{bmatrix}$$

The above three structures capture three different cases of interaction between ULA spatial components and cross-pol components. Mainly, they correspond approximately to the following three cases i) ULA is strictly rank 1 and cross-pole is used to achieve the rank-2 spatial separation, ii) ULA is highly rank 2 and can be used mainly for spatial separation, and iii) all other cases, where ULA and cross-pole both show rank 2 behavior.

In the first structure, the wireless communication device selecting one column vector of the first matrix. The first sub-precoder matrix associated with two spatial layers is obtained then by multiplying the selected column vector with first and second elements in a first row of the second matrix, and the second sub-precoder matrix associated with two spatial layers is obtained by multiplying the selected column vector with first and second elements in a second row of the second matrix.

In the second structure, the wireless communication device selecting first and second column vectors of the first matrix. The first sub-precoder matrix associated with two spatial layers is obtained by multiplying the first column vector with a first element in a first row of the second matrix and multiplying the second column vector with a second element in a first row of the second matrix, and the second sub-precoder matrix associated with two spatial layers is obtained by multiplying the first column vector with a first element in a first second row of the second matrix and multiplying the second column vector with a second element in a second row of the second matrix.

In the third structure, the wireless communication device selecting first and second column vectors of the first matrix. The first sub-precoder matrix associated with two spatial layers is obtained by multiplying the first column vector with a first element in a first row of the second matrix and multiplying the a second column vector with a second element in a first row of the second matrix, and the second sub-precoder matrix associated with two spatial layers is obtained by multiplying the second column vector with a first element in a first second row of the second matrix and multiplying a the first column vector with a second element in a second row of the second matrix.

The illustration above is based on rank 2 or 2-layer precoding. For rank 1 or one-layer precoding, a similar generalized construction of the final precoder could be

$$\begin{bmatrix} v_1 \gamma_1 \\ v_2 \gamma_2 e^{j\theta_1} \end{bmatrix}.$$

A simplified structure that is found to be sufficient for 8 Tx cross-pol antenna configuration rank-1 transmission is

$$\begin{bmatrix} v_1^{nb} \\ v_1^{nb} e^{j\theta_1} \end{bmatrix}$$

where $v_{nb}^1 = f(v_{wb}^1, CB_i)$. Similar generalization/construction can be applied to higher ranks using a combination of co-

phasing vectors, additional wideband precoder components and additional amplitude scalars.

In other embodiments, we provide further description of the component codebooks, and will use rank 2 for illustration, as similar approach applies to other ranks.

In a preferred embodiment, a product matrix based method of precoder matrix representation can be used to describe the two-component feedback.

First component which describes a wideband codebook is expressed as

$$W_1 = \begin{bmatrix} 1 & 1 \\ e^{\frac{2\pi j n_1}{N_1}} & e^{\frac{2\pi j n_2}{N_1}} \\ \cdots & \cdots \\ e^{\frac{2\pi j L n_1}{N_1}} & e^{\frac{2\pi j L n_2}{N_1}} \end{bmatrix}$$

$$n_1, n_2 \in \{0, 1, 2, \ldots N_1 = 2^{B_1} - 1\}$$

which is essentially to capture $[v_1^{wb}\ v_2^{wb}]$. A different size may be chosen for n1 and n2 and further only particular pairs may be allowed to reduce codebook size. In addition, some non-DFT codebook entries may be added to represent each column.

The second codebook may be represented as one of the three forms:

$$W_2 = \left\{ \begin{bmatrix} 1 & e^{\frac{2\pi j k_1}{4}} & 1 & -e^{\frac{2\pi j k_2}{4}} \\ 0 & 0 & 0 & 0 \end{bmatrix}, \right.$$

or

$$\begin{bmatrix} \rho & \sqrt{1-\rho^2}\, e^{\frac{2\pi j k_1}{4}} & 0 & 0 \\ 0 & 0 & \sqrt{1-\rho^2} & \rho e^{\frac{2\pi j k_2}{4}} \end{bmatrix},$$

or

$$\left. \begin{bmatrix} \rho & 0 & 0 & \rho e^{\frac{2\pi j k_2}{4}} \\ 0 & \sqrt{1-\rho^2}\, e^{\frac{2\pi j k_1}{4}} & \sqrt{1-\rho^2} & 0 \end{bmatrix} \right\},$$

where

$$\rho^2 \in \{0.5, 0.75, 0.9, 1\},$$

$$k_1, k_2 \in \{0, 1, 2, 3\}$$

The final precoder is obtained as

$$W = \text{reshape}(W_1 W_2)$$

where a "reshaping" operation is to re-arrange the columns of the product matrix to form the precoder matrix. For example, for 8 Tx with a 4-by-2 W and a 2-by-4 W_2 and 4-by-4 product matrix can be column-wise reshaped to 8×2 precoder W as follows.

$$\text{reshape}(X = [X_1 X_2 X_3 X_4]) = \begin{bmatrix} X_1 & X_3 \\ X_2 & X_4 \end{bmatrix}$$

A more general "reshaping" operation on a matrix represented as a row of vectors can be defined as follows for higher ranks and arbitrary number of antennas.

$$\text{reshape}([X_1 X_2 X_3 X_4 \ldots X_{N \times M}], N, M) = \begin{bmatrix} X_1 & X_{N+1} & \cdots & X_{(N-1)+1} \\ X_2 & \cdots & & \\ \cdots & \cdots & & \\ X_N & X_{2N} & & X_{NM} \end{bmatrix}$$

In another embodiment, additional joint coding of parameters ρ, k_1, k_2 may be performed to restrict the size of the subband codebook by selecting a subset of combinations

enumerated above. Further different entries may also be chosen for the codebook than shown in the embodiment. The three rows in the codebook are chosen to correspond to the three structures for the final precoder matrix. In the first row, the amplitude scalar is set to 1 and co-phasing is reduced to 4 instead of 16, to ensure orthogonality. Similar joint coding can be performed to reduce the entries in other rows corresponding to structures 2 and 3, which may be based on further optimization.

In another embodiment, the subband codebook may be expanded allowing the incorporation of a rotation codebook, in which case the wideband and subband codebook could be represented mathematically as

$$W_1 = \left[\mathrm{diag}\left(\left[\begin{matrix} 1 & e^{\frac{2\pi j n_1}{N_1}} & \ldots & e^{\frac{2\pi j L n_1}{N_1}} \end{matrix}\right]\right), \mathrm{diag}\left(\left[\begin{matrix} 1 & e^{\frac{2\pi j n_2}{N_1}} & \ldots & e^{\frac{2\pi j L n_2}{N_1}} \end{matrix}\right]\right)\right]$$

$$= \begin{bmatrix} 1 & 0 & \ldots & 0 & 1 & 0 & \ldots & 0 \\ 0 & e^{\frac{2\pi j n_1}{N_1}} & \ldots & 0 & 0 & e^{\frac{2\pi j n_2}{N_1}} & \ldots & 0 \\ 0 & 0 & \ldots & 0 & 0 & 0 & \ldots & 0 \\ 0 & 0 & \ldots & e^{\frac{2\pi j L n_1}{N_1}} & 0 & 0 & \ldots & e^{\frac{2\pi j L n_2}{N_1}} \end{bmatrix}$$

$$n_1, n_2 \in \{0, 1, \ldots N_1 = 2^{B_1} - 1\}$$

$$W_2 = \left\{\begin{bmatrix} u_1 & 1e^{\frac{2\pi j k_1}{4}} u_1 & u_1 & -1e^{\frac{2\pi j k_2}{4}} \\ 0 & 0 & 0 & 0 \end{bmatrix}\right.$$

or

$$\begin{bmatrix} \rho u_1 & \sqrt{1-\rho^2}\, e^{\frac{2\pi j k_1}{4}} u_1 & 0 & 0 \\ 0 & 0 & \sqrt{1-\rho^2}\, u_2 & \rho e^{\frac{2\pi j k_2}{4}} u_2 \end{bmatrix},$$

or

$$\left.\begin{bmatrix} \rho u_1 & 0 & 0 & \rho e^{\frac{2\pi j k_2}{4}} u_1 \\ 0 & \sqrt{1-\rho^2}\, e^{\frac{2\pi j k_1}{4}} u_2 & \sqrt{1-\rho^2}\, u_2 & 0 \end{bmatrix}\right\},$$

where

$$\rho^2 \in \{0.5, 0.75, 0.9, 1\},$$

$$k_1, k_2 \in \{0, 1, 2, 3\};$$

$$n = -2^{B_2-1} = -N_2/2, -(N_2/2-1), \ldots 0 \ldots, N_2/2 - 1\}$$

where 0, 1 represent Lx1 vectors of zeros and ones respectively.

The construction above presents a product design followed by reshaping to provide improved flexibility in the two component feedback. However, further overhead reduction can be configured by eNB, by enabling codebook subset restrictions at wideband and subband level. A codebook subset restriction is essentially where eNB signals the UE to only use a subset of codebook entries for the feedback. Subset restriction can be applied to either the first codebook, or the second codebook, or both.

Codebook subset restriction can be used for both wideband and subband components in a pre-configured and compatible manner, which we will further describe with some exemplary methods.

In one embodiment, a subset restriction can be imposed at wideband level to only transmit information regarding v1, by defining wideband codebook as follows

$$W_1 = \left[\mathrm{diag}\left(\left[\begin{matrix} 1 & e^{\frac{2\pi j n_1}{N_1}} & \ldots & e^{\frac{2\pi j L n_1}{N_1}} \end{matrix}\right]\right)\,\mathrm{diag}([\begin{matrix} 1 & 1 & \ldots & 1 \end{matrix}])\right]$$

With this restriction, only B1 bits of information need to be sent, and may be beneficial when ULA is highly rank 1 as in certain LOS cases, and only structure one may be used for all

sub-bands included in the feedback. This would also implicitly result in following restriction for the subband codebook,

$$W_2 = \left\{\begin{bmatrix} u_1 & e^{\frac{2\pi j k_1}{4}} u_1 & u_1 & -e^{\frac{2\pi j k_2}{4}} \\ 0 & 0 & 0 & 0 \end{bmatrix}\right.,$$

$$k_1, k_2 \in \{0, 1, 2, 3\};$$

$$u_1, u_2 \in CB_{ij} = \left\{\left[\begin{matrix} 1 & e^{\frac{2\pi j n}{N_1 K}} & e^{\frac{2\pi j \cdot 2n}{N_1 K}} & \ldots & e^{\frac{2\pi j \cdot L n}{N_1 K}} \end{matrix}\right]^T\right\},$$

$$n = -2^{B_2-1} = -N_2/2, -(N_2/2-1), \ldots 0 \ldots, N_2/2 - 1\}$$

In another embodiment, at subband level, a subset restriction can be imposed to limit to one or more structures.

In another embodiment, a subset restriction can be used to signal wideband value of a parameter. For example, p may be signaled commonly on a wideband basis or as a fixed value common to all codebook entries corresponding to each structure. Similarly, co-phasing may be fixed if structure one is used, so that $k_1 = k_2 = 0$.

In another embodiment, subset restriction can enable/disable further refinement using rotation i.e., u_1 and u_2 can be set to $[1\ 1\ \ldots\ 1]^T$, which corresponds to no rotation of wideband vector.

Additionally, codebook subset restrictions may be imposed in an inter-dependent manner over wideband and subband codebooks. In other words, an UE may receive an UE-specific or cell-specific higher layer subset-restriction parameter which can take a set of multiple values each of which maps to a 'codebook subset' pair for W and W_2. The mapping can be pre-defined and known to both the eNB and the UE. The construction of final precoder is simply based on

$$W = \mathrm{reshape}(W_1 W_2) \tag{0.12}$$

once the component precoders are chosen from the restricted codebooks.

In general, the subset restriction may be useful under certain persistent long-term conditions like whether link is line of sight (LOS) or non line of sight (NLOS), the eNB antenna configuration if a general codebook is used for all configurations (say ULA/XPOL), UE geometry which could limit the uplink feedback link capacity and iv) additional feedback required for other transmission modes like multiuser MIMO which may provision fewer bits to higher-ranked SU transmission.

The two component feedback scheme described above is applicable to multiple feedback modes as further described below.

One embodiment is illustrated in FIG. 6. The first component could correspond to a wideband matrix W_1^{WB} corresponding to the whole bandwidth 610, which is composed of one or more sub-bands 620. Each subband 620 is composed of a set of contiguous subcarriers 630 or in LTE, a set of RBs, which is the minimum scheduling/feedback granularity. A second matrix W_2^b corresponds to a to a band V. The precoder for a band represented as W^b is obtained as a function of W_1^{WB} and W_2^b. A preferred example of the function as described above is reshape (W1×W2). A UE is required to feedback the wideband precoder/matrix for the whole band and the subband precoder/matrix for each subband.

In one embodiment, the feedback could be defined along with an associated CQI feedback. The CQI feedback could correspond to a modulation and coding scheme (MCS) recommendation and/or a rank indication. The CQI could further consist of multiple CQI, one per each subband. In this case, the UE must select the components W_1^{WB} and W_2^b such that the subband precoders can support the CQI reported corresponding to the subband on the hypothesis UE is allocated

that subband, while satisfying an error rate target. In another embodiment, a single CQI may be reported for the whole band, in which case the reported CQI must meet the error rate target, on the hypothesis that the UE is allocated the whole band, and the reported pre-coders are applied on each sub-band.

In another embodiment, the reported sub-bands may be a subset of the sub-bands that constitute the bandwidth and may or may not be equal in size as defined by number of subcarriers in each subband.

In another embodiment, the sub-bands to be reported may be signaled by the eNB explicitly from a set of predefined patterns.

In another embodiment, the sub-bands **620** may also be selected by the UE. The selection could be based on the best N (N<wholebandwidth) bands with ranking defined based on a performance criterion like sum rate supported or similar.

In another embodiment, the first matrix may be further feedback at different time instances and/or periodicities compared to the second matrix. This can, for example, be useful to alleviate the feedback load on the uplink in a single reporting instance like a subframe. Further, they may also be transmitted on different uplink physical channels like PUSCH and PUCCH defined in the current LTE Release-8.

In the above description, we have extensively used DFT based codebooks as preferred examples. If the antennas at the eNB are not calibrated, it is likely that the phase progression as in a DFT vector assumed for a ULA antenna sub-array may not hold. In the worst case scenario of un-calibrated antennas, the relative phase error between antennas may be random. However, it is also expected they are stable and slowly varying compared to time between feedback intervals. Other errors like relative timing errors between antennas may also introduce a relative phase shift that may not correspond to a ULA array. In such cases, one solution is for the UE to feedback a phase error correction vector relatively infrequently, which can be used to rotate the reported precoder at the eNB.

Further, another approach is to include some non-DFT but constant modulus vectors in the wideband codebook, which can compensate for the relative phase error. Note that the subband codebook may not be changed, since it is a relative rotation with respect to the wideband vector.

While the present disclosure and the best modes thereof have been described in a manner establishing possession and enabling those of ordinary skill to make and use the same, it will be understood and appreciated that there are equivalents to the exemplary embodiments disclosed herein and that modifications and variations may be made thereto without departing from the scope and spirit of the inventions, which are to be limited not by the exemplary embodiments but by the appended claims.

What is claimed is:

1. A wireless communication device configured for sending precoder matrix information to a base station, the device comprising:
a transmitter configured for sending the precoder matrix information to the base station, the precoder matrix information comprising:
a first representation of a first matrix chosen from a first codebook and a second representation of a second matrix chosen from a second codebook, the first matrix having at least two column vectors, the first representation and the second representation together conveying a precoder matrix of one or more vectors associated with one or more spatial layers; and

the precoder matrix comprising a first sub-precoder matrix including a first set of weights on a first subset of transmit antennas of the base station and a second sub-precoder matrix including a second set of weights on a second subset of transmit antennas of the base station, the first and the second subsets of transmit antennas of the base station being non-overlapping, the first sub-precoder matrix and the second sub-precoder matrix comprising one or more column vectors of the first matrix corresponding to the first representation multiplied by one or more entries of the second matrix corresponding to the second representation.

2. The wireless communication device of claim **1**, wherein the at least two column vectors are different.

3. The wireless communication device of claim **1**, wherein the first representation is an index of the first chosen matrix from the first codebook.

4. The wireless communication device of claim **1**, wherein the second representation is an index of the second chosen matrix from the second codebook.

5. The wireless communication device of claim **1**, wherein the first codebook includes a set of matrices whose column vectors are Discrete Fourier Transform (DFT) vectors.

6. The wireless communication device of claim **1**, wherein the second matrix has at least two entries that have different and non-zero amplitude.

7. The wireless communication device of claim **1**, wherein the second matrix has a same vector norm for each row of the second matrix.

8. The wireless communication device of claim **1**, wherein the second matrix has a same vector norm for each column of the second matrix.

9. The wireless communication device of claim **1**, wherein the second matrix comprises entries that are co-phasing factors associated with the first sub-precoder matrix and the second sub-precoder matrix.

10. The wireless communication device of claim **9**, wherein the co-phasing factors are based on a Discrete Fourier Transform (DFT) codebook.

11. The wireless communication device of claim **1**, wherein the wireless communication device is further configured for selecting one column vector of the first matrix, wherein the first sub-precoder matrix is associated with one spatial layer and the first sub-precoder matrix is obtained by multiplying the selected column vector with a first element in a first row of the second matrix, and wherein the second sub-precoder matrix is associated with one spatial layer and the second sub-precoder matrix is obtained by multiplying the selected column vector with a first element in a second row of the second matrix.

12. The wireless communication device of claim **1**, wherein the wireless communication device is further configured for selecting one column vector of the first matrix, wherein the first sub-precoder matrix is associated with two spatial layers and the first sub-precoder matrix is obtained by multiplying the selected column vector with first and second elements in a first row of the second matrix, and wherein the second sub-precoder matrix is associated with two spatial layers and the second sub-precoder matrix is obtained by multiplying the selected column vector with first and second elements in a second row of the second matrix.

13. The wireless communication device of claim **1**, wherein the wireless communication device is further configured for selecting first and second column vectors of the first matrix, wherein the first sub-precoder matrix is associated with two spatial layers and the first sub-precoder matrix is obtained by multiplying the first column vector with a first

element in a first row of the second matrix and multiplying the second column vector with a second element in a first row of the second matrix, and wherein the second sub-precoder matrix is associated with two spatial layers and the second sub-precoder matrix is obtained by multiplying the first column vector with a first element in a second row of the second matrix and multiplying the second column vector with a second element in a second row of the second matrix.

14. The wireless communication device of claim **1**, wherein the wireless communication device is further configured for selecting first and second column vectors of the first matrix, wherein the first sub-precoder matrix is associated with two spatial layers and the first sub-precoder matrix is obtained by multiplying the first column vector with a first element in a first row of the second matrix and multiplying the second column vector with a second element in a first row of the second matrix, and wherein the second sub-precoder matrix is associated with two spatial layers and the second sub-precoder matrix is obtained by multiplying the second column vector with a first element in a second row of the second matrix and multiplying the first column vector with a second element in a second row of the second matrix.

15. The wireless communication device of claim **1**, wherein the wireless communication device is further configured for:

  forming an alternative form of the second matrix from entries of the second matrix;
  obtaining a product matrix from multiplication of the first matrix and the alternative form of the second matrix; and
  obtaining the precoder matrix performed by mapping columns of the product matrix to the first and second sub-precoder matrix.

16. The wireless communication device of claim **15**, wherein the alternative form of the second matrix is obtained by mapping entries of the second matrix such that one entry is present in each column of the alternative form of the second matrix with remaining entries of each column being zero.

17. The wireless communication device of claim **1**, wherein the wireless communication device is further configured for rotating at least one vector of the first matrix according to a rotation matrix selected from a rotation codebook.

18. The wireless communication device of claim **17**, wherein the rotation codebook is a Discrete Fourier Transform (DFT) codebook.

19. The wireless communication device of claim **17**, wherein the wireless communication device is further configured for rotating at least one column vector of the first matrix according to a rotation matrix chosen from a rotation codebook, wherein the rotation matrix corresponds to a sub-band.

20. The wireless communication device of claim **1**, wherein the first matrix is chosen from a subset of the first codebook.

21. The wireless communication device of claim **1**, wherein the second matrix is chosen from a subset of the second codebook.

22. The wireless communication device of claim **1**, wherein the wireless communication device is further con-

figured for determining a number of column vectors in the precoder matrix, the number of column vectors corresponding to a number of the one or more spatial layers.

23. The wireless communication device of claim **1**, wherein the first matrix corresponds to a frequency band, the second matrix corresponds to a frequency sub-band within the frequency band, the first representation and the second representation together convey the precoder matrix of one or more vectors associated with the one or more spatial layers, and the precoder matrix corresponds to the frequency sub-band.

24. A method of precoding at a base station based on feedback from a wireless communication device, the method comprising:

  receiving feedback conveying a recommended precoder from the wireless communication device, the feedback comprising a first representation of a first matrix chosen from a first codebook and a second representation of a second matrix chosen from a second codebook, the first matrix having at least two column vectors, the first representation and the second representation together conveying a precoder matrix of one or more vectors associated with one or more spatial layers;
  constructing a final precoder as a function of the received feedback;
  precoding at least one data stream using the final precoder; and
  transmitting the at least one data stream from the base station to the mobile communication device.

25. The method of claim **24**, wherein the at least two column vectors are different.

26. The method of claim **24**, wherein the first representation is an index of the chosen matrix in the first codebook.

27. The method of claim **24**, wherein the second representation is an index of the chosen matrix in the second codebook.

28. The method of claim **24**, wherein the first codebook includes a set of matrices whose column vectors are Discrete Fourier Transform (DFT) vectors.

29. The method of claim **24**, wherein the second matrix has at least two entries that have different and non-zero amplitude.

30. The method of claim **24**, wherein the precoder matrix comprises a first sub-precoder matrix including a first set of weights on a first subset of transmit antennas of the base station and a second sub-precoder matrix including a second set of weights on a second subset of transmit antennas of the base station, the first and the second subsets of transmit antennas of the base station being non-overlapping, the first sub-precoder matrix and the second sub-precoder matrix comprising one or more column vectors of the first matrix corresponding to the first representation multiplied by one or more entries of the second matrix corresponding to the second representation.

31. The method of claim **30**, wherein the second matrix comprises entries that are co-phasing factors associated with the first sub-precoder matrix and the second sub-precoder matrix.

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